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VARIABLE STARS OF THE ALGOL TYPE.

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The interesting articles referred to in the last number of POPULAR ASTRONOMY, on the Densities of the Algol Variables, by Messrs. Alexander Roberts and Henry Norris Russell*, led the writer to brush up his knowledge of this class of variable stars, and it was thought that some of the results of his study might be put in such form as to be interesting to the readers of the magazine. What is written is therefore presented with no claim to originality or a thorough study of the subject. We venture to hope, however, that it may be of use in putting clearly before the minds of perhaps some of the professional astronomers as well as of the average reader, the problem of interpreting the varying light of these peculiar stars.

These variables are regarded as exceedingly close double stars, whose light variation is caused by the eclipse of one star by the other. The planes of their orbits must be nearly parallel to the line of sight from the Earth to the star, so that each star in the course of a revolution will pass between the Earth and the other star, cutting off its light in part or wholly, just as the Moon eclipses the Sun. The parallel will be much better if we can imagine two suns close together, revolving about each other so swiftly that every few days or hours the one passes in front of the other. When they are separated, side by side, we receive the light from the whole hemisphere of each of them, and their combined light is at a maximum. When they are so nearly in line with the Earth that the disc of one appears to overlap that of the other, part of the light of the more distant star is cut off and their combined light is diminished. If the stars are equal in diameter and the one passes directly in front of the other, for a moment there is a total eclipse of the more distant star and the eye receives only the light of the nearer one. If the orbit be circular, under these conditions there are two equal minima of the star during each revolution, the intervals between them are equal and the periods of waning and increase of light are equal.

* *Astrophysical Journal* Vol. X, p. 308-318.

Under the same conditions, if the two stars are of equal surface brightness, the greatest diminution of their total light will be 0.8 of a magnitude, for in case of a total eclipse of either by the other only half of their total light will be cut off. Since a star of a given magnitude on Argelander's scale is approximately 2.5 times as bright as one of the next lower magnitude, to divide its light by 2 would reduce its magnitude by $2/2.5 = 0.8$.

In case the two stars are of equal surface brightness but of unequal diameters, the light at either minimum, if the eclipse be central, is very nearly equal to that from the larger star and hence the diminution of light will be less than 0.8^m. So when the components are of equal surface brightness, there can be no very marked minima. If the difference in size is very great the minima will be scarcely noticeable.

On the other hand, when one of the stars is darker than the other, the minima will be unequal, and may be so unequal that one will not be observable at all, while at the other the star may become nearly or quite invisible.

When the orbit of one star about the other is elliptic, as is usually the case, there are two minima which may be equal or unequal according to the inclination of the orbit and the relative brightness of the component stars. The intervals between the two minima of each revolution are generally unequal; the exception being when the major axis of the ellipse lies in the line of sight from the Earth to the star.

The figures, which we have prepared, will perhaps enable the reader to understand more clearly the statements already made, and prepare the way for those which will follow. In Fig. 1, Plate IV, we will suppose the circle A to represent a bright star, and B a smaller or darker star, both revolving in circular orbits around their common center of gravity C. Let EA be a portion of the line of sight from the Earth to the star. If this line of sight lie in the plane of the orbits $AA'A''$ and $BB'B''$, it will be clear that every time B passes the position B_2B_3 it must be projected in perspective against A, as shown in Fig. 2, Plate IV, obscuring a surface area of A whose projection is equal to the projection of the earthward surface of B. Also when A reaches A'', B will be at B'' and will be wholly obscured by A. Between those positions as at $A'B'$ the stars will send their combined radiation earthward.

It will be easier to study the relative movements of the two stars if we transfer the center of movement to the center of the bright star and ascribe the whole change of position to the lesser star. The orbit of B about A will then be the larger circle $B_1B_5B_9$.

This circle represents truly the relative movement of B, for clearly AB_5 is equal both in length and direction to $A'B'$, and $A''B''$ has its counterpart in the line between AB_1 and AB_8. The angular movement of B is the same in both cases, but its linear velocity in the relative orbit is the sum of the real velocities of A and B.

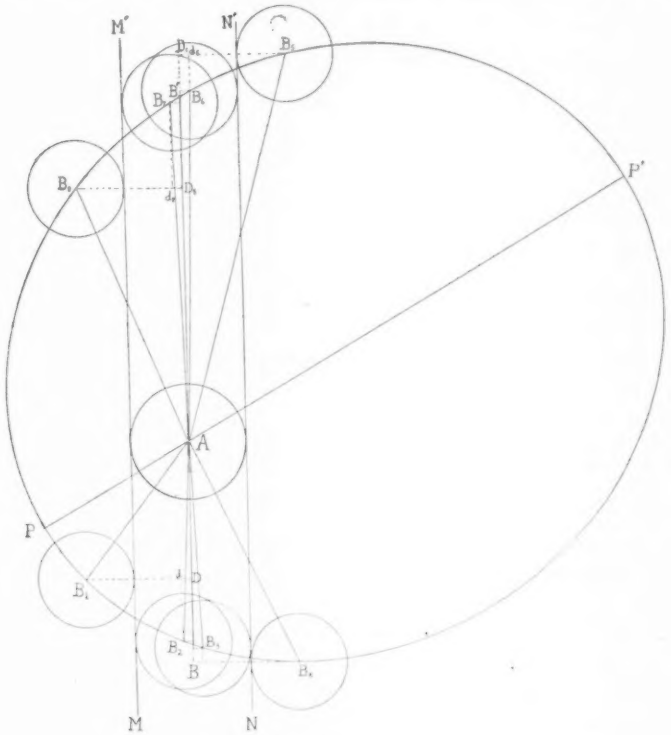


FIG. 3. ELLIPTIC ORBIT OF AN ALGOL VARIABLE.

Using then the larger circle and regarding A as stationary, we may draw the parallel lines MN and $M'N'$ tangent to the disc of A as the limits of a cylinder within which B must enter in order to eclipse A on the one hand or be eclipsed on the other. Supposing the eclipse to be central and taking no account of the atmospheres of the stars (a most important omission), as soon as B reaches the position B_1, tangent to MN, the light begins to wane; slowly at first, then more rapidly, as the longer chords of B encroach upon A, then more slowly until at B_2, the whole disc of B

overlaps that of A and the light is at a minimum. The minimum will continue, practically stationary, until B reaches B_3, tangent to $M'N'$, when the increase of light will begin, the order of change being the reverse of that of the waning, ending at B_4. From B_4 to B_6 the light will be constant, but from B_6 to B_9 a secondary minimum will occur, the light of B being cut off by A, waning from B_6 to B_7, stationary from B_7 to B_8 and increasing from B_8 to B_9. From B_9 to B_1 the light will remain constant again. Thus one will readily see that a variable of this class should have two minima and that generally the two minima should be unequal. Only in case the two stars are of equal surface brightness can the two minima be equal. In that case the brightness at both minima is practically that of the star A, for at the primary minimum B gives about as much light as it cuts off from A, while at the secondary minimum the light is wholly that of A.

The reader must understand that these stars are so distant from the Earth that they are mere points as seen through the most powerful telescopes and that the distance between the components is far below the limit of measurement with a micrometer. No one of them has ever been seen double in a telescope. Very little therefore can be determined with reference to their orbits. The fact of their being double was a mere inference from the phenomena of their light variations, until a few years ago. In 1888-9, Professor Vogel,* by a series of photographs of the spectrum of Algol proved that that star was moving away from the Earth before each minimum at the rate of 24.4 miles per second and was approaching at the rate of 28.5 miles per second after each minimum, proving conclusively that it was revolving about a center of gravity under the control of a force from a dark companion.

The other variables of this type are all fainter than Algol and their orbital motions have not, so far as I am aware, been determined spectroscopically, so that we must confine ourselves to what can be learned from their light changes and the similarity of these changes to those of the one known to be binary.

First, then, let us connect the light curve of Algol at minimum with the orbital velocity determined by Vogel. For about 59 hours Algol's light is practically constant, shining as a star of 2.3 magnitude. Nearly five hours before minimum it begins to decline, slowly at first then more rapidly, until at minimum its magnitude is about 3.4. It then increases in the reverse order of

* *Astronomische Nachrichten*, No. 2947.

its decline, a very little more slowly perhaps, recovering its normal brightness in a little less than five hours, the total duration of the light change being about $9^h\ 45^m$. The curve of those changes, as determined by Dr. Scheiner from all available observations during the last two centuries, is shown in Fig. 4. Supposing the transit of the companion star to be central over the primary and the orbit to be circular, it is evident from Fig. 1 that the sum of the diameters of the two stars is equal to the

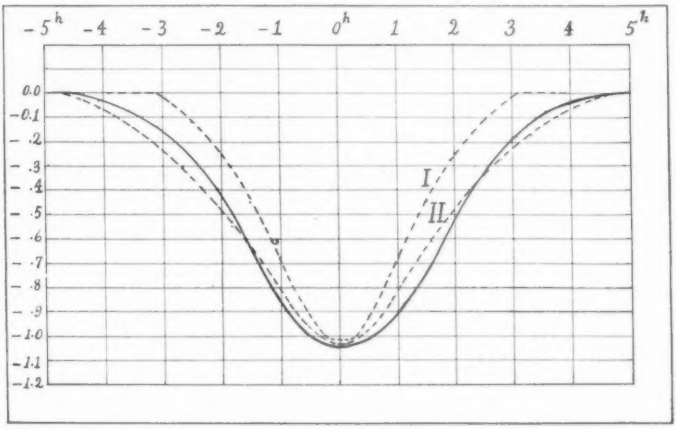


FIG. 4. LIGHT CURVES FOR ALGOL.

line B_1B_4, or the sum of their radii is one-half of that line. Representing the radius of A by a, that of B by b and that of the orbit by R, the duration of light variation by d and the total period of the variable by p,

$$a + b = R \sin \frac{1}{2} B_1AB_4 = R \sin \frac{1}{2} \frac{2\pi d}{p}. \qquad (1)$$

If the orbit be elliptic, as in Fig. 3,

$$a + b = r_1 \sin (v_0 - v_1) = r_4 \sin (v_4 - v_0) \qquad (2)$$

where r_1, r_4, v_1 *and* v_4 are the radii vectores and the true anomalies of the points B_1 and B_4, and v_0 the true anomaly of the point B, which can be computed by the usual elliptic formulæ when the elements are known.

Confining ourselves to the circular orbit, which is very nearly true in the case of Algol, and adopting Vogel's mean orbital velocity 26.3 miles per second and Chandler's period $2^d\ 20^h\ 48^m\ 55^s = 247{,}735^s = 68.814^h$ we have

$$R_c = \frac{26.3 \times 247{,}735}{2\pi} = 1{,}040{,}000 \text{ miles};$$

that is, the principal star is about one million miles from the center of gravity of the system. Assuming, from the loss of light at a minimum of about 1 magnitude, that the surfaces are in the ratio of 1.00 to 0.60, we should have for the ratio of the diameters of the stars 1 to 0.78; and for their volumes 1 to 0.475 or approximately 0.5. Again assuming, what may or may not be true, that their densities are equal, their masses will be in proportion to their volumes and their distances from the center of gravity will be as 1 to 2. So we may take in round numbers for the distance of the primary star from the center of gravity 1,040,000 miles, for the distance of the satellite from the center of gravity $1{,}040{,}000 \div 0.475 = 2{,}190{,}000$ miles, and for the distance of the center of the satellite from the center of the primary star 3,230,000 miles. The sum of their radii then becomes

$$a + b = R \sin \frac{d}{p} \cdot \pi = 3{,}230{,}000 \sin \left(\frac{9.75}{68.81} \times 180^\circ \right) =$$

1,390,000 miles.

Dividing the sum in the ratio of 1 to 0.78 we have $a = 781{,}000$ miles and $b = 609{,}000$ miles.

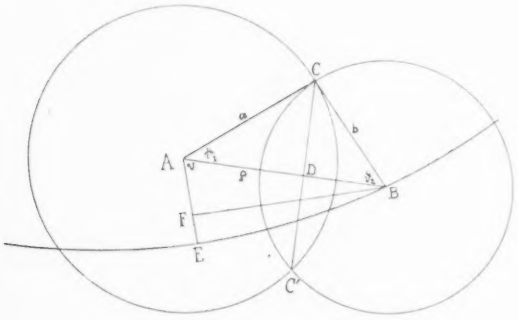


Fig. 5.

Let us now see how these dimensions of the two stars will satisfy the light curve. In Fig. 5 let BE be the projection of a portion of the orbit of the satellite B near conjunction with A. If the transit were central, the distance AE would be zero; in general it is $R \sin i$, where i is the inclination of the line of sight to the plane of the orbit. In the case of Algol the light is not stationary for any noticeable length of time at the minimum, so that

the transit cannot be central. Let us assume that the inclination is just enough to cause the disc of B to wholly enter upon that of A, producing internal tangency at minimum; then

$$R \sin i = a - b \text{ and } \sin i = \frac{a-b}{R}. \qquad (3)$$

Let $\rho =$ the projection of AB and $u =$ the angle BAE, then at any moment

$$\rho = \sqrt{R^2 \cos^2 u \sin^2 i + R^2 \sin^2 u} \qquad (4)$$

If t represent the time occupied by the satellite in passing from E to B

$$u = \frac{t}{p} \times 360°. \qquad (5)$$

The area from which the light is cut off at any moment is the sum of the two segments between the chord and the two arcs CC'. The segments are the differences between the corresponding sectors and triangles ACC' and BCC'. The areas of the sectors are

$$\text{Sector } ACC' = \pi a^2 \left(\frac{2\theta_1}{360°}\right) \text{ and Sector } BCC' = \pi b^2 \left(\frac{2\theta_2}{360°}\right)$$

in which θ_1 and θ_2 represent the angles BAC and ABC respectively. The areas of the triangles are

$$\Delta ACC' = a^2 \sin \theta_1 \cos \theta_1 = \frac{a^2 \sin 2\theta_1}{2} \text{ and}$$

$$\Delta BCC = b^2 \sin \theta_2 \cos \theta_2 = \frac{b^2 \sin 2\theta_2}{2}.$$

From these we obtain for the area of the eclipsed portion of the primary star

$$S = \frac{a^2}{2}\left(\frac{2\theta_1}{57.3°} - \sin 2\theta_1\right) + \frac{b^2}{2}\left(\frac{2\theta_2}{57.3°} - \sin 2\theta_2\right). \qquad (6)$$

The angles θ_1 and θ_2 may be found by the formulae

$$\cos \theta_1 = \frac{\rho^2 + a^2 - b^2}{2a\rho} \text{ and } \cos \theta_2 = \frac{\rho^2 - a^2 + b^2}{2b\rho}. \qquad (7)$$

If the loss of light be considered proportional to the area of the covered part of the disc and the satellite gives no appreciable light we may express the ratio of the brightness at any moment to the normal brightness by

$$L = 1 - \frac{S}{\pi a^2} \qquad (8)$$

and the loss in magnitudes by

$$\Delta m = \frac{10}{4} \log L. \qquad (9)$$

By the aid of these formulae I computed the values of Δm for Algol for the five hours before and after minimum, with the values $a = 781{,}000$ miles and $b = 609{,}000$ miles. In the computation, however, I expressed a and b in terms of R by dividing each by 3,230,000. R then became unity in the formulae and $a = 0.2415$ and $b = 0.1885$. The values of Δm found agreed exactly with those computed in a similar manner by Dr. J. Wilsing† and are represented by the lower dotted curve *II* in Fig. 4. It will be noted that this curve nowhere deviates more than 0.10 magnitude from the observed light curve. The small deviation is however systematic and larger than the errors of the observed curve. Dr. Vogel considered that the observations could

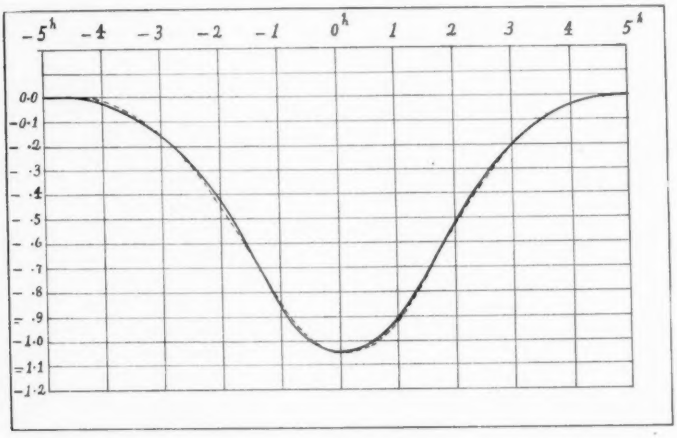


FIG. 6. WILSING'S COMPUTED LIGHT-CURVE OF ALGOL.

be better represented by supposing the two stars to be smaller in diameter but surrounded by extensive atmospheres, the absorption of which changes the character of the curve. He estimated the radii of the two stars as $a = 530{,}000$ and $b = 415{,}000$ miles. The upper dotted curve *I* in Fig. 4 represents the light changes, which I have computed with these dimensions of the stars, neglecting the effect of their atmospheres. The duration of the light change would be only $6^h\ 30^m$ and there would be a stationary period of a half hour or more at the minimum.

† *Astronomische Nachrichten* No. 2960.

Dr. Wilsing by using Vogel's radii of the stars and assuming that the atmospheres surrounding the stars extended to the limits which in our first computation we gave to the stars themselves, *i. e.* to 781,000 miles and 609,000 miles from the respective centers, was able to represent the observed light curve in all parts within 0.02 magnitude, the coefficient of absorption which he deduced being only one-fortieth of that of the Earth's atmosphere. In Fig. 6 I have platted his final values, in which he made a small correction for the eccentricity of the orbit, which he found to be 0.011, together with the observed light curve. The dotted line here coincides so closely with the smooth line that it was difficult to draw them so as to show both. No more complete representation of observation by theory could be asked for.

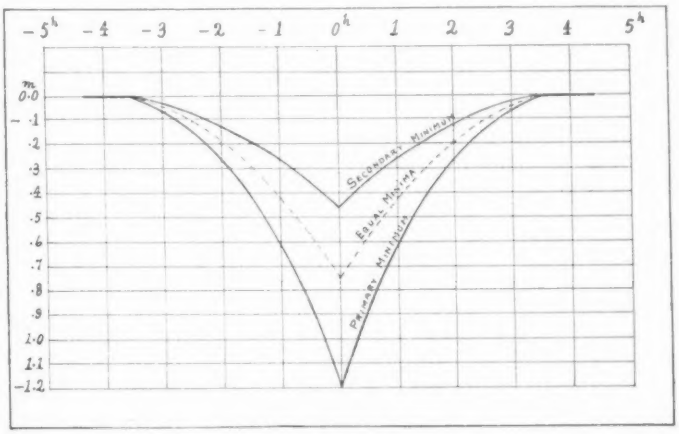


Fig. 7. Theoretical Light-curves.

In the first part of his investigation Dr. Wilsing takes up the question of the possibility of two such bodies existing in so close proximity and shows that the deformation of one of the bodies by the attraction of the other amounts to only one-ninetieth part, which is much less than the flattening of Jupiter by its own rotation. He also shows that if the satellite shines by reflected light only, its brightness cannot be more than $\frac{1}{510}$ of that of the primary star and therefore it could have no influence upon the light curve. That its light is very feeble is evident from the fact that Algol has no secondary minimum. Dr. Plassman* thinks he has observed slight changes in the light of Algol be-

* *Astronomy and Astrophysics* Vol XI, p. 419.

tween minima. These changes are very slight and must be explained in some other way than by the eclipse theory, for he finds two secondary minima, neither of them anywhere midway between the primary minima.

In Fig. 7 I have drawn some theoretical curves, which, though having no basis in actual observation, may assist in comprehending the problem. The dotted curve was computed on the hypothesis of two stars, without atmospheres, equal in diameter and intensity of surface luminosity, revolving about each other, or rather their common center of gravity, at the distance of the components of Algol. The curve is the same for both minima. The two smooth line curves were computed on the same hypothesis as above, with the exception that surface intensity of one of the stars is twice that of the other. The transits are supposed to be central in each case and the diameters 1,060,000 miles. The sharp points of the curves at minima can be rounded off either by assuming atmospheres or by supposing the

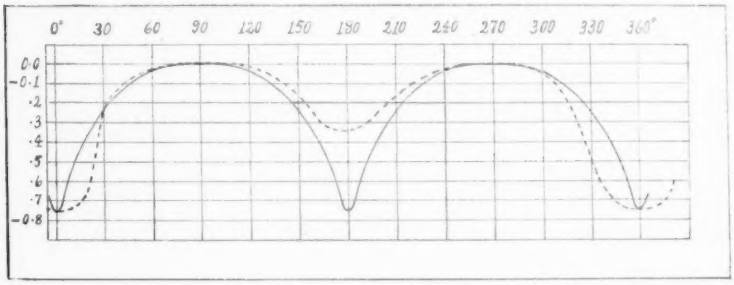


FIG. 8. LIGHT-CURVE OF EQUAL STARS IN TANGENCY, AND OF β LYRÆ.

eclipses to be only partial. The symmetry of the curve before and after minimum may be destroyed either by eccentricity of the orbits of the stars or by elongation of the bodies themselves, provided that elongation be not exactly parallel to the line joining their centers. In Fig. 8 the smooth curve represents the light variation, during an entire revolution, of two stars of equal intensity of surface illumination and equal diameters, revolving tangent to each other. This is an impossible case, for the mutual attractions of the two bodies would destroy their spherical figure and cause the contiguous portions to merge, forming figures perhaps like the ellipsoid of Jacobi, the dumb-bell or the apioid of Poincaré, figures which have been shown to be of at least temporary stability of equilibrium*. The curve bears so

* See POPULAR ASTRONOMY, Vol. III, pp. 489-519.

much resemblence however to the curve of β Lyrae, which I have drawn as the dotted line in the same Figure, that it would seem that by proper assumptions as to the forms, distance, intensity and atmospheres of the two components, the variations of that star and all of its class might be represented on the eclipse theory. In this class of variables the light change is not confined to a relatively short portion of the period, near minimum, but is continuous throughout the whole period. This would be the result with the Algol variables if the components should be near enough together for their atmospheres to blend.

Dr. Chandler has shown† that the period of Algol is variable, having decreased, with several fluctuations, up and down, from $2^d\ 20^h\ 48^m\ 58^s.0$ to $2^d\ 20^h\ 48^m\ 51^s.1$ during the last century. He attempts to account for this change by the attraction of a second dark body in the system, and is inclined from his study of the problem to regard the mass of this second companion as greater than that of the bright star. We should thus have the anomaly of a bright satellite revolving about a dark primary body, which is certainly a very interesting cosmological problem, much as we may doubt its possibility. From an investigation of the proper motion of Algol, Dr. Chandler thinks he has found evidence of this orbital motion of the bright star, and that its period is about 131 years and the semimajor axis of the orbit $1''.33$. There are also slight indications of disturbances by still other hypothetical dark companions, in other words perhaps of a complex planetary system akin to the solar system. M. Tisserand, however, denies the necessity of assuming the dark primary body and shows that the observed change of period can be accounted for by the attraction of a smaller dark body, if one or both of the close companions are flattened by rotation. His theory also requires the presence of the third member, and possibly more, of the system.

Similar irregularities in the length of period are found in the case of several others of the Algol-type variables, and suggest the same explanation, so that we may, perhaps, naturally conclude that motions like those shown to exist in the case of Algol, and furnishing evidence of complex planetary systems, somewhat similar to that of the Sun, are not rare exceptions but possibly the rule in the stellar universe.

There is another irregularity in the light changes of certain of these stars, however, which seems more difficult of explanation

† *Astronomical Journal* Vols. VII, p. 180; IX, p. 121. See also POPULAR ASTRONOMY Vol. V, p. 302.

and almost fatal to the satellite theory. That is well shown in the light curve of U Ophiuchi in Fig. 9; a distortion of the curve shortly after minimum, due to something which checks the recovery of light for a time. This retardation is so slight that, if it were noticed in one star or by one observer alone, it might be regarded as due to some fault in the observing. But it seems to be characteristic of several of the Algol stars and Chandler speaks of noticing the same tendency in Algol. It must, therefore, be taken into account in any theory which is to explain the changes of these peculiar stars.

LIGHT CURVE OF U OPHIUCHI.

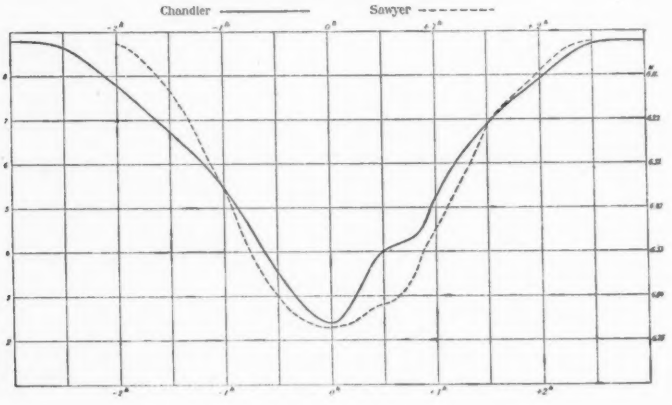


FIG. 9.

In order to obtain any idea of the absolute masses of the bodies, we must know their actual distances or parallaxes and the elements of their orbits. Rough approximations to their maximum densities, however, as compared with the Sun, may be obtained even when these are lacking, from the data of the light variations. Assuming the law of gravitation to be the same in other systems as in our own, when two bodies have satellites, the ratio of their masses is determined by the proportion*

$$M + m : M_1 + m_1 :: \frac{r^3}{t^2} : \frac{r_1^3}{t_1^2} \qquad (10)$$

in which M and M_1 are the masses of the primary bodies, m and m_1 the masses of the satellites, r and r_1 the distances of the satellites from their respective primaries, and t and b their periodic times. From this

* Young's General Astronomy. p. 342.

$$\frac{M_1 + m_1}{M + m} = \frac{t^2 r_1^3}{t_1^2 r^3}. \qquad (11)$$

Adopting the mass of the Sun as unity and neglecting that of the Earth, since it is insignificant in comparison, expressing the time in units of a year, and taking the Earth's mean distance from the Sun as 93,000,000 miles, we have

$$M_1 + m_1 = \frac{r_1^3}{t_1^2\,(93{,}000{,}000)^3}. \qquad (12)$$

Since the density of a body is its mass divided by its volume, the density of a star and that of the Sun will be in the proportion of their masses divided by the cubes of their diameters, or

$$\delta_a : \delta_s :: \frac{M_a}{a^3} : \frac{M}{s^3} \qquad (13)$$

where δ_a is the density of the star, δ_s that of the Sun, a and s their diameters and M_a and M their respective masses. In units of the Sun's mass and density

$$\delta_a = \frac{s^3}{a^3} M_a \qquad (14)$$

If δ represent the average density of the two components of a binary, whose diameters are a and b

$$\delta = \frac{s^3}{a^3 + b^3}\,(M_a + M_b). \qquad (15)$$

Substituting the second member of equation (12) for $(M_a + M_b)$ and 866,400 miles for s, we obtain

$$\delta = \frac{\left(\frac{866{,}400}{93{,}000{,}000}\right)^3 r_1^3}{t_1^2\,(a^3 + b^3)} = \frac{(0.0093)^3\, r_1^3}{t_1^2\,(a^3 + b^3)}. \qquad (16)$$

Evaluating (16) for Algol, taking Vogel's dimensions of the system, we get

$$\delta = \frac{(0.0093)^3\,(3{,}230{,}000)^3}{\left(\frac{68.81}{24 \times 365.25}\right)^2 (1{,}061{,}000^3 + 830{,}000^3)} = 0.249;$$

that is, the average density of the components of Algol is only one quarter of that of the Sun.

If we should include the atmospheres in the volumes of the stars, which is what we must do when we have no other data than the light curve, in the case of Algol $a^3 + b^3$ would be $(1{,}562{,}000^3 + 1{,}218{,}000^3)$ and we should obtain $\delta = 0.078$.

In formula (16) let $a = pr_1$ and $b = qr_1$. Then

$$\delta = \frac{(0.0093)^3}{t_1^2(p^3 + q^3)}. \qquad (17)$$

The values of p and q may be found from the light variations of the star. In Fig. 1

$$B_1D = \frac{1}{2}(a + b) = r_1 \sin \frac{1}{2} B_1AB_4 = r_1 \sin \frac{\pi d}{t_1},$$

and

$$D_2D = \frac{1}{2}(a - b) = r_1 \sin \frac{1}{2} B_2AB_3 = r_1 \sin \frac{\pi c}{t_1}.$$

in which t_1 is the total period of the variable, d is the duration of the change of light, and c is the period during which the light remains constant at minimum. Adding and subtracting, we have

$$a = r_1\left(\sin \frac{\pi d}{t_1} + \sin \frac{\pi c}{t_1}\right)$$
$$b = r_1\left(\sin \frac{\pi d}{t_1} - \sin \frac{\pi c}{t_1}\right).$$

Dividing by r_1,

$$p = \left(\sin \frac{\pi d}{t_1} + \sin \frac{\pi c}{t_1}\right),$$
$$q = \left(\sin \frac{\pi d}{t_1} - \sin \frac{\pi c}{t_1}\right). \qquad (18)$$

If the star has no interval of constancy at the minimum, c is zero and p and q are equal. Formula (17) then becomes

$$\delta = \frac{(0.0093)^3}{2t_1^2 \sin^3 \frac{\pi d}{t_1}}$$

and if we express t_1 and d in hours instead of years

$$\delta = \frac{(0.0093)^3 \times 24^2 \times 365.25^2}{2t_1^2 \sin^3 \frac{\pi d}{t_1}} = \frac{30.9}{t_1^2 \sin^3 \frac{\pi d}{t_1}} \qquad (19)$$

This will give Mr. Russell's formula if we multiply it by 1.39, the density of the Sun in units of the density of water.

If p and q are unequal we may obtain maximum estimates of the densities of the individual stars in the following manner.

Dividing equation (14) by (15)

$$\delta_a : \delta = (a^3 + b^3) M_a : a^3 (M_a + M_b)$$

Hence

$$\delta_a = \frac{(a^3 + b^3)\delta}{a^3}\left(\frac{M_a}{M_a + M_b}\right)$$

and substituting for δ its value from (16) and cancelling r_1, as in (17)

$$\delta_a = \frac{(0.0093)^3}{p^3\, t_1^2}\left(\frac{M_a}{M_a + M_b}\right) \qquad (20)$$

In like manner

$$\delta_b = \frac{(0.0093)^3}{q^3\, t_1^2}\left(\frac{M_b}{M_a + M_b}\right) \qquad (21)$$

Now the fractions $\frac{M_a}{M_a + M_b}$ and $\frac{M_b}{M_a + M_b}$ must always be less than unity, no matter how small one of the masses may be, and if one of these fraction approaches unity the other must approach zero. If the masses are equal the two fractions each become equal to ½. Hence if we substitute unity for the final factors in equations (20) and (21) we shall have as maximum expressions for the densities of the component stars,

$$\delta_a = \frac{(0.0093)^3}{p^3\, t_1^2} \text{ and } \delta_b = \frac{(0.0093)^3}{q^3\, t_1^2} \qquad (22)$$

These are Mr. Roberts' formulae, except that he has 0.0092 instead of 0.0093 in the numerators of the expressions.

If in these formulae we express t_1 in hours instead of years they will be a little more convenient for use. We have then

$$\delta_a = \frac{61.8}{p^3 t_1^2} \text{ and } \delta_b = \frac{61.8}{q^3 t_1^2} \qquad (23)$$

which correspond with (19).

As an example of the working of the formulae let us take X Carinae, which Mr. Roberts finds to vary very regularly. It is constant for 6½ hours at 7.8 magnitude, declines in 3¼ hours to $8^m.6$ and recovers in 3¼ hours. As there is no constant period at maximum and the fall is just 0.8 magnitude or one-half the total light, we may consider this as a binary of two equal components, the total period being 26 hours with equal minima at equal intervals. We have then $t_1 = 26^h$, $c = 0$, $d = 6.5$, whence $p = 0.707$ and $q = 0.707$.

Therefore, $$\delta_a = \frac{61.8}{p^3 t_1^2}\left(\frac{M_a}{M_a + M_b}\right) = 0.259\left(\frac{M_a}{M_a + M_b}\right)$$

and $$\delta_b = \frac{61.8}{q^3 t_1^2}\left(\frac{M_b}{M_a + M_b}\right) = 0.259\left(\frac{M_b}{M_a + M_b}\right);$$

or, if the masses be assumed equal, the densities of both stars equal 0.130 of the Sun's density.

A most remarkable result is obtained in the case of S Velorum, a southern star, the normal magnitude of which is 7.8, but which

sinks at minimum to 9.3 and remains constant at the minimum for 6½ hours. The elements of its variation are

	d	h	m	s
Total period	5	22	24	23
Descending period		4	10	0
Constant at minimum		6	30	0
Ascending period		4	10	0

It is evident that the fainter star is larger than the brighter one and thus totally eclipses the latter for 6½ hours. There ought to be a noticeable secondary minimum, but Mr. Roberts makes no reference to any observations of it. If the orbit be circular we have

$$t_1 = 142^h.41 \qquad d = 14^h.63 \qquad c = 6^h.50$$
$$p = \sin 18°.4 + \sin 8°.2 = 0.46 \text{ (for faint star).}$$
$$q = \sin 18°.4 - \sin 8°.2 = 0.14 \text{ (for bright star).}$$
$$\delta_a = \frac{61.8}{p^3 t_1^2} = 0.03 \text{ (for faint star).}$$
$$\delta_b = \frac{61.8}{q^3 t_1^2} = 0.61 \text{ (for bright star).}$$

Thus the maximum limit for the density of the faint star is only one-thirtieth that of the Sun.

Considering the orbit as possibly elliptic Mr. Roberts finds the following expressions for the densities, letting e equal the eccentricity and θ the angle between the line of apsides and the line of sight:

$$\text{Density of bright star} = 0.61 \left(\frac{\sqrt{1-e^2}}{1+e\cos\theta}\right);$$

$$\text{Density of faint star} = 0.031 \left(\frac{\sqrt{1-e^2}}{1+e\cos\theta}\right);$$

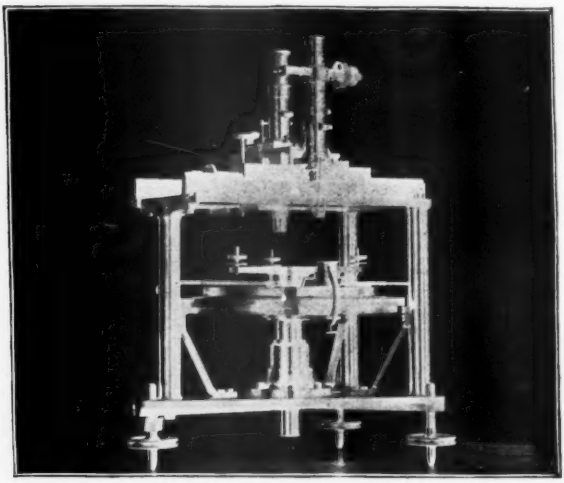
"The relation between the diameters of the stars and the axis-major of the orbit precludes a higher eccentricity than 0.5, for any greater value would mean collision at periastron passage. Also it is evident that the greatest value of the density is obtained when $\theta = 180°$. Considering now the value of the eccentricity to be the greatest possible; and eclipse to take place at periastron, then the greatest possible values of the densities of the two stars become

Bright star	3.17
Faint star	0.16.

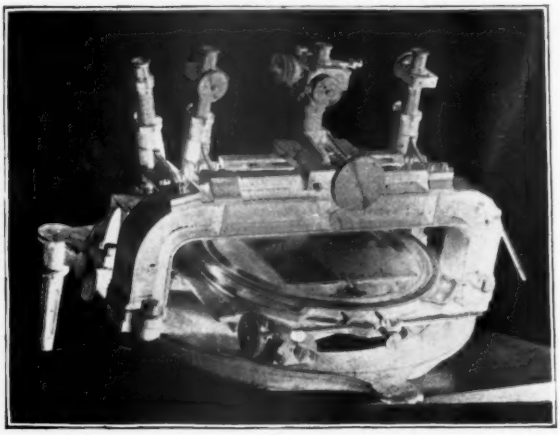
That both these values are far too great is certain. They assume a high eccentricity. The regularity of the light curve is directly against this assumption. They assume a value of the mass of either star infinitesimally small. But with every possible combination of mass, position in orbit and eccentricity, the density of the faint star is still exceedingly small."

PLATE V.

MACHINES FOR MEASURING ASTRONOMICAL PHOTOGRAPHS.



THE RUTHERFURD.



THE REPSOLD.

THE RUTHERFURD PHOTOGRAPHS.

FLORA E. HARPHAM.

For Popular Astronomy.

Photography claims the respectable age of twenty decades, though astronomical interest in its development took a practical turn only at the beginning of the last six of the twenty. When the experimenters were at a loss to find a solvent for the salts of silver on the undarkened portion of their plates which would at the same time leave untouched the darkened parts, Sir John Herschel led them out of their difficulty by suggesting the use of hypo-sulphite of soda for the double purpose of fixing and clearing. The suggestion proved valuable and the obstacles which had hindered the development of photography practically disappeared. The substitution of glass as a support for the sensitizing salts and the adoption of collodion as a medium to hold the chemicals upon the glass plate rendered the success of photography assured. The modern "dry plate" has been evolved of late years but the old collodion or "wet process" gave exceedingly fine results.

If Sir John the chemist made the suggestion which helped so much the material development of the new art, Sir John the astronomer was equally quick to realize the advantage of this aid to progress. He advised the use of the sensitive plate for the self-registry of Sunspots and lived long enough to see photography bid fair to outrival the slower and less reliable method of eye obsevation of objects to which it is adapted. Before his death many photographs had been taken, not only of the Sun and Moon, but also of the stars and star spectra.

Among those who entered with enthusiasm upon the new lines of investigation was a young man of New York, Lewis M. Rutherfurd. By a fortunate combination of circumstances, just when photography became serviceable, he was enabled to give up his law practice and devote his whole energy to scientific investigation. During his course at Williams College, he had given much time to chemistry and physics and shown also great mechanical skill. He accordingly planned his work along these lines, spent several years in study and travel in Europe, and returned home with the intention of devoting himself to astronomical and optical investigation. He built an Observatory in the garden of his home and began the work which he continued for twenty years and which made his name well known in the scientific circles of Europe and America.

Mr. Rutherfurd was obliged to construct his own instruments. While engaged in spectroscopic work, he devised a ruling engine which produced interference gratings unequalled until Professor Rowland's ruled surfaces appeared. In the investigation of star spectra Mr. Rutherfurd discovered the amount of correction necessary to convert an achromatic object glass into a photographic lens. By means of this discovery, he constructed a large photographic telescope of eleven inches diameter, and later a still larger one of thirteen inches. From the time of the completion of his first telescope, Mr. Rutherfurd was indefatigable in his astronomical activity. He used, of course, the wet plate process and became expert in the delicate manipulations necessary to ensure sharp negatives full of detail. His photographs of the Moon, especially, are scarcely surpassed in their exquisite definition even by the modern appliances of the great Observatories of today. In the twenty years of his photographic activity he took a large number of plates of the Sun, Moon, star groups and spectra, and received many acknowledgements of their excellence. He had the satisfaction of seeing his long labor appreciated by the scientific world and realized that the success of his work had much to do with the practical development of astronomical photography. He was firmly convinced of its value and labored unweariedly to prove its excellence. He originated the method and introduced its practical working; he devised and constructed the first measuring micrometer for photographs and caused a large number of measures of his plates to be executed in his study under his own supervision. When his health failed, he carried the machine and plates and measurer with him to the south, that the work which he had planned should not be interrupted. In the year 1890, he gave to Columbia University nearly fifteen hundred of his finest negatives together with his telescope, measuring micrometer and entire Observatory equipment.*

Through the courtesy of Professor Rees, Director of the Observatory, a photograph of the Rutherfurd measuring micrometer and of the modern Repsold machine accompany this article. The essential parts of both machines consist of a microscope micrometer, a graduated circle and a graduated scale. In the Rutherfurd machine a second microscope is rigidly attached to the frame of the first for the purpose of reading the scale when the micrometer threads of the first microscope are bisecting a star. The two microscopes move parallel to each other along

* Lewis M. Rutherfurd, by John K. Rees, *Astronomy and Astro-Physics*, Oct., 1892.

the length of the plate, but a transverse motion in its frame is also possible to the first microscope, thus allowing it to move across the plate as well as lengthwise. By this device, any star on the plate may be brought under the micrometer threads. The plate rests upon a glass circle and the circle upon three levelling screws. When the glass circle is rotated, the plate is carried around with it. Outside the glass circle is a fixed graduated silver circle read by a microscope which records the position angles from the central star. The plate is set into the machine in such a position that the central star will remain under the microscope when the plate is rotated. The scale reading is noted for the central star and the micrometer is then moved over any other star, the scale microscope recording the reading for the second star also. The difference of the readings gives the distance between the stars. Although the machine will permit the measurement of either rectangular or polar coördinates, Mr. Rutherfurd preferred the latter and all the measures made under his supervision are in the form of distances and position angles from the central star. The distances are obtained as just described, but to find the position angle it is necessary to know the "zero of position" as the point is called from which the angles are measured. This is determined by Mr. Rutherfurd's method of exposing the plate. He took two impressions of all the stars and three impressions of the brighter ones. After the first impression was made, he screened the plate from the starlight and moved the telescope slightly westward, thus throwing the second impression east of the first. When this second impression was completed, the clock was disconnected from the telescope and the stars were allowed to pass across the plate, the bright ones leaving a fine, black line to record their course. It required a very bright star to trace this line which extended from the eastern image back through the western and across the plate to the third image; for when the stars had approached the edge of the plate, the clock was again started and the telescope was held long enough to permit the brighter stars to leave a third impression. This last image was called the "trail" and marked the direction of increasing right ascension, thus giving the needed "zero of position" for the angles.*

Mr. Rutherfurd's custom of placing a known star in the centre of his photographic plate was one of the best evidences of the excellence of his method. For the fundamental problem in the re-

* Reduction of Photographic Observations, Dr. B. A. Gould. Nat. Acad. of Sciences, Vol. IV.

duction of photographic measures is to deduce the right ascension and declination of the stars in the sky from their measured coördinates on the plate. This requires that the position of the origin of coördinates should be known. This origin coincides with the foot of the perpendicular let fall from the optical centre of the object glass upon the plate. The photographic plate is a plane surface and upon it is projected that portion of the celestial sphere represented by the stars which dot the surface of the photograph. The plate may be regarded as a tangent plane, and the point on the plate which represents the point of tangency is the foot of the perpendicular let fall from the centre of the object glass. Mr. Rutherfurd so adjusted his plate in the holder that the image of the central star should lie approximately at the foot of this perpendicular. And as he always selected for the central star one which is well known, the position of the origin of the coördinates was thus determined.

The modern Repsold measuring machine differs from the Rutherfurd only in its details. The photograph of the Repsold shows a plate in the machine in position for measurement. One of the three legs of the machine has been removed, allowing the frame to fall forward until it rests upon its edge, thus placing the plate at an angle to the plane of the supporting table, in which position it is more conveniently measured. Instead of moving the measuring micrometer both longitudinally and transversely as in the Rutherfurd machine, the longitudinal motion is communicated to the plate itself by means of the large screw of the machine which moves the plate-carrying casting along a guiding cylinder. The microscope moves transversely along a carriage at right angles to the cylinder and parallel to the scale. By means of these two motions any star on the plate may be brought under the micrometer threads and its position noted by the scale, the difference of the scale readings for the star and the central star giving its distance from the latter. One microscope reads both the star and the scale, as the lever lifts the microscope through a small angle. After setting the micrometer threads upon a star, the micrometer is turned upon the scale by means of this small angular motion and the distance of the star from the nearest division of the scale is measured directly by the graduated head of the micrometer screw. In either rectangular or polar coördinates, the distances are measured in this manner, but the position angle from the central star is obtained from the reading of the graduated circle on the outer edge of the casting which carries the plate. In the

Repsold machine the orientation of the plate is a simpler process than that described above for the Rutherfurd. By means of the slow motion screw the plate is moved until both the central star and its trail will remain under the micrometer threads during a motion of the plate along the cylinder. By turning the graduated circle ninety degrees and clamping the plate in this position, the direction of increasing right ascension is found to be very nearly parallel to the scale. It will not be exactly parallel, owing to the diurnal motion of the star during the exposure of the plate, the size of the small angle between the two depending on the declination of the star. After the circle reading is corrected for this small angle, the central star will then lie approximately at the origin of the coördinates, the positive axis of X will point toward the east and the positive axis of Y toward the north; the final small correction necessary to place the origin at the foot of the perpendicular let fall from the centre of the object glass is found later by a least square solution from the measures themselves.

Mr. Rutherfurd's gift of his instruments to the university was accompanied by the volumes containing the measures which he had caused to be executed. Most of these were as yet unreduced. As early as 1865, however, he had prevailed upon his friend, Dr. Benjamin A. Gould, to take sufficient time from the duties of an active professional life to enable him to reduce some of the measures in order to test the accuracy of the photographic method. Dr. Gould selected for this purpose the measures of the group of the Pleiades, being influenced to this choice by the fact that a heliometer determination of their relative positions had been made by Bessel. The accuracy of these heliometer positions would give a severe test of the photographic reduction.

In the selection of the formulas for these reductions, Dr. Gould followed the general outline for the reduction of heliometer measures.* He wished to consider also in his discussion the sources of possible errors, such as a motion of the collodion film by shrinkage or expansion, the effect of irregularity in the motion of the clockwork guiding the telescope, the distortion of the images near the edge of the field, and the errors of measurement caused by the different aspects of the stars in different positions of the plate in the measuring machine, inasmuch as the images vary in density and it is difficult for the eye to select the exact centre. At the time of Dr. Gould's discussion the method was new and some

* Reduc. of Phot. Observations, B. A. Gould, Nat. Acad. of Sciences, Vol. IV.

fear was felt, especially in the matter of durability, lest the photographic plate would hold its usefulness for only a comparatively short period. But Dr. Jacoby has shown, by a remeasurement and discussion of some of the Pleiades plates twenty years after the photographs were taken, that the film does not deteriorate from age and its records may therefore be relied upon.*

In the formulas of reduction, Dr. Gould considered the relations of the parts of the spherical triangle formed upon the sky by the north pole, a star, and the point in the sky corresponding to the centre of the plate.

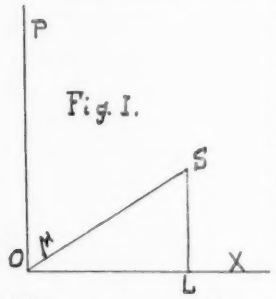


Fig. 1.

In Figure 2, PS is the polar distance of the star, PC is the polar distance of the point corresponding to the centre of the plate, CS is the distance, η, of the star from C, the angle SPC is the difference in right ascension between the star and the centre, and the angle PCS is the position angle, μ, of the star.

In the plane triangle considered in Figure 1, PO is the projection of the meridian PC. OS is the projection of the distance η. POS is the position angle μ which remains unchanged since PC and CS, being arcs of great circles are projected upon the plane surface as straight lines which are the tangents of the circles; OL and SL are the measured x and y of the star upon the plate. Then, considering the ordinary trigonometrical formulas of the spherical triangle, from Figure 1.

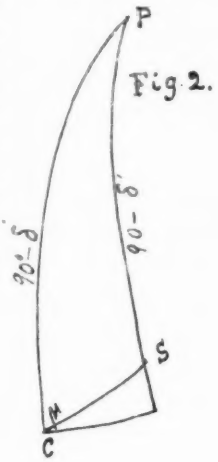


Fig. 2.

$$\sin\eta\sin\mu = \cos\delta'\sin(\alpha'-\alpha)$$
$$\sin\eta\cos\mu = \cos\delta\sin\delta' - \cos\delta'\sin\delta\cos(\alpha'-\alpha)$$
$$\cos\eta = \sin\delta\sin\delta' + \cos\delta\cos\delta'\cos(\alpha'-\alpha)$$

and from Figure 2,

$$x = \tan\eta\sin\mu$$
$$y = \tan\eta\cos\mu$$

$$\text{whence } x = \frac{\cos\delta'\sin(\alpha'-\alpha)}{\sin\delta\sin\delta' + \cos\delta\cos\delta'\cos(\alpha'-\alpha)}$$

* Permanence of Rutherfurd Phot. Plates. Harold Jocoby, Ann. of New York Acad. of Sciences, Vol. IX.

$$y = \frac{\cos\delta \sin\delta' - \cos\delta' \sin\delta \cos(\alpha' - \alpha)}{\sin\delta \sin\delta' + \cos\delta \cos\delta' \cos(\alpha' - \alpha)}$$

From these equations the approximate values of $(\alpha' - \alpha)$ and $(\delta' - \delta)$ may be obtained in terms of x and y which have been measured upon the plate, or in terms of distance and position angle if they are preferred. Rigorous values of $(\alpha' - \alpha)$ and $(\delta' - \delta)$ may be derived from these same equations by expansion into a series of ascending powers of x and y.

These formulas of Dr. Gould are identical with the modern formulas of Sir Robert Ball and Dr. Arthur Rambaut with the exception of the factor r which is the radius of the sphere to which the plate is tangent, r being equal to the equivalent focal length of the telescope.* The reduction to the final form for logarithmic computation differs in the latter also from that of Dr. Gould, but his satisfactory results, when compared with Bessel's heliometer determination of the Pleiades positions, speak well for both the Rutherfurd photographs and the method.

In the reductions, the measures are first freed from instrumental errors depending upon the division errors of the scale, errors of the micrometer screw and runs. Upon every plate are a few, at least, known stars. After correcting the measures for refraction and multiplying the measured coördinates by the scale value in seconds of arc, the corrected coördinates will agree very nearly with the differences obtained by subtracting the catalogue position of the central star from that of each of the other known stars. The difference is caused, aside from the errors of observation, by the fact that the origin does not lie exactly at the foot of the perpendicular, by the inexact orientation of the plate, by a possibly incorrect scale value, etc. All these errors are small and by a comparison of the measured positions of the known stars with those deduced from the catalogue, a series of equations of condition is formed whose solution will give the needed corrections to these quantities. The measured coördinates of the unknown stars are then multiplied by these corrected values of the scale, orientation, etc., and from these corrected coördinates are deduced the final differences of right ascensions and declinations.

The photographic plate gives the relative positions of the stars as they appear at the moment when the photograph is taken. As the same region of the sky is photographed on different dates,

* Relative positions of 223 stars in the cluster of χ Persei as determined photographically, Sir Robert Ball, LL. D., F. R. S., and Arthur A. Rambaut, M. A., D. Sc. Trans. Royal Irish Acad. Vol. XXX, pt. IV.

the right ascensions and declinations deduced from each plate must be referred to the beginning of some selected year, usually the year of the plate or the middle year of the series, in case the photographs extend over several years. To refer the stars to this selected epoch, a correction for aberration must be applied to the apparent right ascensions and declinations given by the plate to reduce them to the true, and a further correction for nutation and precession to reduce them to the mean right ascensions and declinations at the beginning of the year of the plate. To bring these to the beginning of another year, the annual precession is applied for the number of years required. The mean of all the values reduced to the same epoch gives the final right ascensions and declinations.

Since Mr. Rutherfurd's gift to the university, many of the plates have been measured and reduced and catalogues made of the stars. The work is still going on but even with rapid measurement, it will require years for the complete reduction of all the star photographs. Before his death Mr. Rutherfurd had the satisfaction of seeing the work well under way. He had the further gratification of seeing the field in which he was a pioneer well occupied by trained workers. In 1886 he was invited to attend the international conference which met at Paris for the purpose of considering the charting of the entire heavens by means of photography. Although prevented by failing health from attending, Mr. Rutherfurd was an interested observer of the action of that conference and approved the great undertaking which, when completed, will be a valuable legacy to the astronomers of future generations.

UNIVERSITY OF COLUMBIA,
February 1, 1900.

THE STUDY OF ASTRONOMY. III.

W. W. PAYNE.

In the January issue of this publication, (p. 24), we referred to the lack of interest manifested by leading teachers and educators in the study of elementary astronomy and offered some reasons why so general a view should prevail. We also tried to point out the disadvantage, if not harm, that has arisen from such an erronious view.

In the last number, (p. 75) more was said in regard to this

same point, giving a few illustrations of what has seemed to the writer strong evidence to sustain the position taken, and then began the reference to what is claimed to be improved methods of study and instruction for college and secondary schools. We called attention to the usefulness of simple observation of some heavenly bodies, saying that such work, if properly arranged and followed up by teacher and student, will always awaken an interest in study that it may not be easy to secure in any other way. Not only so, but if the plan is persistently followed, and faithfully used, step by step, will surely lay the foundation of a habit of observation that will be of life-long value to its possessor, because having eyes to see he has acquired the power to grasp more than others when he looks at anything worthy of attention.

The next point made was the advantage of good illustration. In this the thought is that the student shall get his eyes and mind away from the words of the book, which is rightly his guide for the statement of principle, fact or definition; so as to get a different and a firmer impression in mind of the thing he is to comprehend, without the necessity of learning words out of a book which may not convey meaning enough in themselves to hold them easily.

In the study of the Moon a good chart is desirable, indeed necessary for the best results, if the instructor has not the advantage of a small telescope. In illustrating the Sun, our experience in the use of large photographs has been very satisfactory. Such pictures show the photosphere in detail, so that there can be no doubt concerning its lack of continuity, its faculæ, its spots, large and small, in their varying structure, something of the filaments of the penumbra, the bridges of the umbra, the rotation of the Sun from day to day, by the apparent movement of the spots across the disc, the direction of the solar axis in the same way, and the difference of intensity of the light of the Sun from its limb and its central regions. These and many other things are easily seen by inexperienced eyes if the collection is large enough to include the different phases of solar activity that will cover at least one half of a rotation period when the spot conditions are favorable. We have not yet made a complete series of these pictures, though we have prepared enough of them so that the main points desired are illustrated and others have been easily inferred from what could be seen from the partial series. Some teachers have used a series of Sun-spot drawings to some extent, though no drawings can so well show the conditions of spots as is possible

with photography. If any instructor should care to make a comparison of a series of such drawings with photographs that are now made almost daily, those by Father Sistini and published first by Lieut. M. F. Maury, Director of the United States Naval Observatory, in the publications of that institution for the year 1847, and printed in 1853. They will be found in Vol. III, appendix A. That number of these publications and others preceding it are comparatively scarce and may not be easily obtained. The drawings are beautiful specimens of art and the engravings show a degree of skill worthy of high commendation. I have no doubt but that those desiring copies of this work as a means of illustration, or for library uses might obtain them at small expense by writing to Professor J. G. Hagan, S. J., of Georgetown College Observatory, Georgetown, District of Columbia.

A still more effective way for the study of the Moon and the Sun is by the aid of lantern slides under a strong light. It may be thought too expensive to provide secondary schools with a good stereopticon and an oxy-hidrogen light for the sake of illustrations in the department of science, but it seems to us that it is wise economy to do this, not only for the science work, but also because the same apparatus can be effectively used in illustrating art and literature studies and even those of language and history. The time is coming and we hope soon, when eye, ear and pencil will more equally share in making mental impressions than has been true in the past, except in some particular branches of study more highly favored in method than others.

The lantern slide furnishes the best means of study of the surface of the planets, because it is easy to make these slides from the current, scientific publications that issue regularly from the leading Observatories of the world, and the persons having such facilities can certainly know and get the very best information and the best results in print almost as soon as it is published.

The character of these drawings is such as to command attention. It is generally true that the best modern astronomical work comes from Observatories that are endowed and have a number of observers in their respective organizations who are trained men in special lines. When any piece of work is completed, or reaches a stage of advancement that knowledge of it will be useful to others, or of general popular interest, it will not generally be difficult to secure such information for publication in channels that are safe for its dissemination. This has been particularly true of all recent, astronomical work for the last twenty years. When Schiaparelli made his notable discoveries in regard to the canals of Mars in 1887-8, it was soon known from one end

of the world to the other. Not long after a fine colored map of the entire surface of the planet was published, so that knowledge of what was supposed to be discovered was very widely known and definitely within the reach of astronomers. The same was true of Professor Asaph Hall's brilliant discovery of the satellites of Mars in 1877, of Mr. Barnard's matchless victory in the capture of Jupiter's fifth satellite, of Mr. Lowell's remarkable discoveries regarding the surface markings on the planet Mars, and for like astonishing results in the study of the surfaces of the planets Mercury and Venus.

These are a few instances relating to the studies of the Moon, Sun, and planets which must interest teachers who desire to have within reach the latest and the best information possible, for the work they, themselves, wish to do for the persons or classes they are appointed to instruct. We have recently published in these pages the fine charts of the markings on the surfaces of the planets Mercury and Venus; also, within the last two years much pertaining to the planet Mars, and good illustrations of the surface views of the planet Jupiter by Professor G. W. Hough of Dearborn Observatory, Evanston, Ill., who probably has done more extended and careful work in observing that planet than any other American astronomer.

Now, if professors in the colleges and instructors in the secondary schools would take up this matter systematically and thoroughly, there can be no question regarding the large results—very unexpectedly large results—that will follow such an undertaking.

We will try to furnish the lantern slides and the large photographs as indicated elsewhere in our advertising pages, as promptly as possible after the wishes of those desiring them are known, and give such other sources of information as we have to aid in carrying out the plan suggested in these articles. If the order for slides or photographs should be large, some delay may be necessary to secure the material, because we use only that which is fresh from the makers and it takes about ten days to secure new photographic supplies from Philadelphia or St. Louis.

We have been interested and encouraged, not a little, in the way some prominent teachers have regarded this series of brief articles so far. A considerable number have already ordered the first two volumes of POPULAR ASTRONOMY at the low price of *one dollar each*, to professors and teachers, for the purpose of trying this plan. We believe the investment is a wise one. Next time we will speak of other work possibly reaching the comets, stars, and the nebulæ.

THE TWENTIETH CENTURY*.

Years *ab urbe condita* (A. U. C.) are years counted out from the supposed date of the foundation of the City of Rome. These years are given according to Varro, the greatest authority on that chronology; but the old calendar of the Romans fitted the years like a bad clock fits the time. The calendar was sometimes too fast, sometimes to slow. Not only was the calendar a bad fit for the course of the years, but it was made a foot ball of by political factions, who, being trusted with its occasional correctness, sometimes put it on and sometimes put it back, in order to facilitate their electioneering tricks, and with only secondary regard for keeping the calendar in beat with the course of the seasons.

Some forty-seven years before Christ, Julius Cæsar—the then Dictator of Rome, and one of the greatest men of antiquity—the man who did Britain the service of conquering it twice, and introducing to it the Roman language, laws, and civilization—had his attention called to the vast inconvenience of this state of the Roman calendar, which was then some three months too fast, and indicated the time of spring when the season was really midwinter. He added some ninety days to the calendar for the year 46 B. C., and made that year of the calendar to extend over 445 days, which, in effect, put back the calendar some 90 days. Julius Cæsar then made the year 45 B. C.† to commence on the first of January, on the day of a new Moon. In order also to make the calendar keep better time, he took up the odd quarter of a day by making every fourth year into what we now call a leap-year. This was one of the great services done by Julius Cæsar to the world, and the calendar thus defined with a year of 365 days, but with every fourth year of 366 days, was called the Julian calendar. The seventh month of the year was named Julius, in honor of Julius Cæsar.

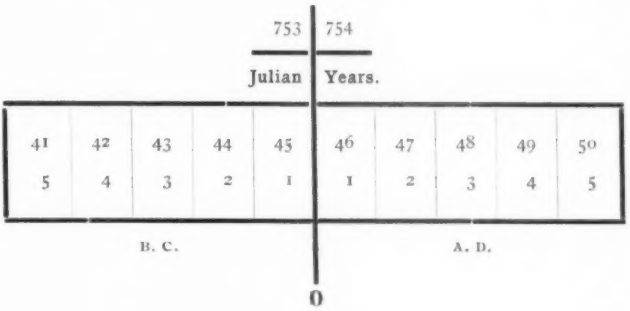
The precise length of the real year was not then known; but subsequently the continual revolution of the seasons showed that the Julian calendar was a little too slow. This was because, as we now know, the length of the year is 365¼ days *minus* $11^m\ 12^s.43$. Every recurring leap-year, therefore, left the Julian calendar nearly 45^m behind time. But the Julian year was very nearly the real year, and it was so vast an improvement upon the former calendar that the years from the 1st of Janu-

* By Dr. James Edmunds in the *English Mechanic*, 1900, Jan. 28.

† [709 A. U. C.—EDS.]

ary of the first Julian year (45 B. C.) were regarded as the Julian era. Now, the diagram shows that decade of Julian years which covers the period from the end of the 40th Julian year to the end of the 50th, each year being indicated by a space which represents the interval *in time* covered by that particular year. According to the chronology of Varro, the 45th and 46th years of the Julian era were more or less contemporaneous with the 753rd and 754th years from the foundation of Rome. These years are indicated in the diagram by the two top numbers.

Ab Urbe Condita (*Varro*).



The end of the 45th Julian year was the date adopted by the Monk Dionysius Exiguus in the year A. D. 527 as the commencement of the Christian era. It therefore follows that the 45th Julian year was the first year before the commencement of the Christian era, and that the 46th Julian year was the first year after the commencement of the Christian era. The decade of years of the Julian era from 41 to 50 inclusive was thus contemporaneous with the first five years before Christ (B. C.), and the first five years after Christ (A. D.). If, now, the diagram be considered by the light of this explanation, and the spaces be regarded as representing the respective years, it should be easy to see "what it is that we are talking about."

The putting in of the leap-years of the Julian era fell into the hands of the priests. They blundered over it, and for the first 36 years of the Julian calendar they put in a leap-year every third year instead of every fourth year. The priests managed this by something like the method of Lord Dundreary, who discovered that whether he had ten fingers on his two hands—or nine, or eleven—depended solely upon whether he counted his

fingers forwards or backwards, and where he left off before he summed them up. Whether the priests began, as some sages of this day do, with a zero year, I do not know. But they counted both extremes, as was the custom in Rome, and so made every three years into four. The result was that in the 37th Julian year, the Emperor Cæsar Augustus discovered that the calendar was too slow by three days, and he then ordered that the next three leap-years should be omitted. Now the next three leap-years would have been 40, 44, and 48 of the Julian era, and these were all reduced to 365 days each. It was not till the fourth leap year, the fifty-second Julian year, and the seventh of the Christian era, that another year of 366 days was let into the calendar. Thus it came about that leap-years were non-existent in the Julian calendar at the commencement of the Christian era.

Owing to the Julian calendar, with its leap-years, proving too slow for the years by an annual interval of $11^{m}\ 12^{s}.43 = 44^{m}\ 49^{s}.72$, or nearly 45 minutes every leap-year, the calendar had got twelve days behind the true season of the year in the time of Pope Gregory. By that time the true length of the year was more accurately known, and Pope Gregory then put the calendar on ten days, so as to correct it for the days it had fallen behind, while, in order to make the calendar in future to keep better time with the revolutions of the Earth round the Sun, he ordained that all the centurial leap-years, except such as were divisible by 400, should be left out. This was in 1582. The Julian calendar, thus further corrected, thenceforth was very unfairly called the Gregorian calendar. What the Monk Dionysius Exiguus had done in 527 was simply to steal the Julian Era. Its first 45 years he cut off, and its 46th he called the first of the Christian era. Otherwise it remained the Julian calendar. And all that Pope Gregory had done was to partly make those further corrections in the number of leap-years which the Julian calendar in its working for centuries had shown to be necessary. The Catholic countries in general at once adopted the New Style (N.S.) of Pope Gregory. This reformed calendar was ten days in advance of other nations, and the unreformed calendar, for the sake of distinction, had to be denoted as Old Style (O.S.). England, being a Protestant country, did not then adopt Pope Gregory's New Style, nor his omitted leap-years. But in 1752 England did this by Act of Parliament (24 Geo. II. c. 23). Russia, being under the sway of the Greek or Eastern church, has even rejected the reformed calendar till this day. Christmas Day, which we held on our Dec. 25, was therefore in Russia the

13th of December. Again, owing to the 1900th year with us having its leap-year omitted, while in Russia it is still a leap-year, as ordained by Julius Cæsar, their calendar will be 13 days behind time on their first of March, 1900. Anglo-Russian documents therefore have to carry two dates in order to avoid confusion. The dates will appear thus:—

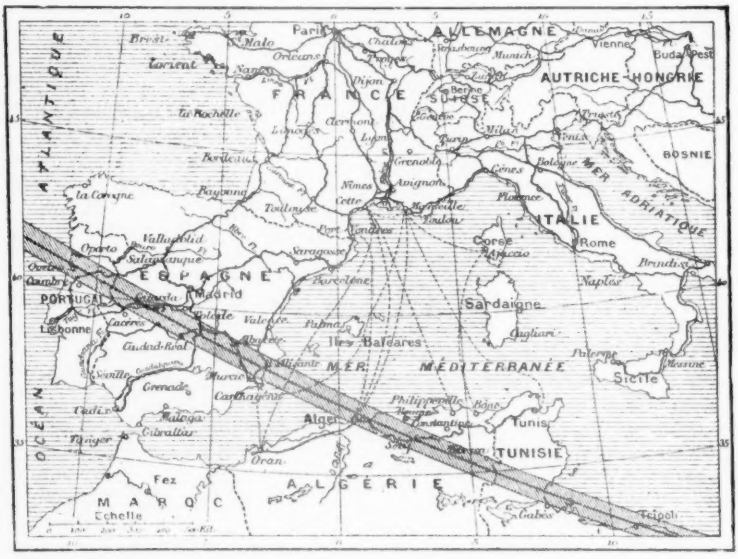
$$\text{Thursday, 1900, March } \begin{matrix} 2 \text{ O.S.} \\ 15 \text{ N.S.} \end{matrix}$$

Reverting now to our diagram, it will be evident that the years B. C. are merely a retrospective method of labelling time, and that, in counting the years B. C., we count backwards, and in each year we unavoidably begin with the 31st of December, and end with the 1st of January. The years A. D. we count forwards, precisely as we count the years of a man's age, and the early calendar A. D. we regard precisely as we regard the calendar to-day. It is, therefore, evident that the 100th year has to be completed before the 1st century is finished, and that the 1900th year has to be completed before the 19th century is finished. When we come to nineteen hundred *and* one we shall have completed the 19th century and entered upon the first year of the 20th.

As to the sticklers for the precise moment of the real Nativity, we know neither the day nor the month of the Nativity. Historians, moreover, are agreed that Christ must have been born prior to February in the fourth year B. C. But whether Christ were born five years before the date now in use for the commencement of the Christian era, or were born five years after it, or had never been born at all, makes not a particle of difference. Our calendar has been determined by an English Act of Parliament, and it would be alike impracticable and futile for us now to attempt to alter it. Nor does the naming nor dating of our era have anything to do with the number of years which have to be allotted to a century. If a cheque for £100 be misdated, that makes no difference to the number of sovereigns which the payee is entitled to at the bank counter. So, in order to complete a century, we must finish up its 100th year to the last moment.

THE APPROACHING TOTAL ECLIPSE OF THE SUN.

The astronomers of both Europe and America are now busy in making arrangements to observe the total eclipse of the Sun which will occur on the 28th of next May. As usual, our American cousins are better off than we are, for they can observe the eclipse without going out of their own country. British astronomers will have to travel to Spain or Portugal. The eclipse path stretches from the west of New Orleans to Algiers and N. Africa on the east. The local times and conditions at certain points along this path are thus given in the "Local Particulars" published by the *Nautical Almanac* Office:—



MAP OF ECLIPSE PATH 28 MAY 1900.*

Position W. of New Orleans.
Long. 90° 6′ W., Lat. 30° 4′ N.

	Local Mean Times. d	h	m	s	Central Standard Mean Times. d	h	m	s	Sun's Altitude. °
Eclipse begins	May 27	18	26	13	May 27	18	26	37	18
Totality begins	" 27	19	29	42	" 27	19	30	6	30
Totality ends	" 27	19	31	0	" 27	19	31	24	
Eclipse ends	" 27	20	43	10	" 27	20	43	34	46

Duration of Totality $1^m\ 17^s.8$.

* From the January Bulletin de la Societé Astronomique de France.

Angle from N. point of first contact, 104° towards the W.
Angle from N. point of last contact, 76° towards the E.
Angle from Vertex, of first contact, 40° towards the W.
Angle from Vertex, of last contact, 145° towards the E.
} for *direct* image.

Position near Union Point, Georgia.
Long. 83° 5′ W., Lat. 33° 29′ N.

	Local Mean Times. d h m s	Central Standard Mean Times. d h m s	Sun's Altitude. °
Eclipse begins	May 27 19 0 25	May 27 18 32 45	25
Totality begins	" 27 20 7 52	" 27 19 40 12	39
Totality ends	" 27 20 9 24	" 27 19 41 44	
Eclipse ends	" 27 21 26 16	" 27 20 58 36	55

Duration of Totality, 1m 32s.

Angle from N. point, of first contact, 104° towards the W.
Angle from N. point, of last contact, 76° towards the E.
Angle, from Vertex, of first contact. 41° towards the W.
Angle, from Vertex, of last contact, 139° towards the E.
} for *direct* image.

Position south of Cape Henry, Virginia.
Long. 76° 5′ W., Lat. 36° 42′ N.

	Local Mean Times. d h m s	Central Standard Mean Times. d h m s	Sun s Altitude. °
Eclipse begins	May 27 19 36 35	May 27 19 40 55	33
Totality begins	" 27 20 48 7	" 27 20 52 27	47
Totality ends	" 27 20 49 53	" 27 20 54 13	
Eclipse ends	" 27 22 11 2	" 27 22 15 22	62

Duration of Totality, 1m 45s.6.

Angle from N. point, of first contact, 103° towards the W.
Angle from N. point, of last contact, 78° towards the E.
Angle from Vertex, of first contact, 44° towards the W.
Angle from Vertex, of last contact, 130° towards the E.
} for *direct* image.

Position near Ovar (Portugal)
Long. 8° 38′ W., Lat. 40° 50′ N.

	Local Mean Times. d h m s	Central Standard Mean Times. d h m s	Sun's Altitude. °
Eclipse begins	May 28 2 8 35	May 28 2 43 7	56
Totality begins	" 28 3 27 10	" 28 4 1 42	42
Totality ends	" 28 3 28 43	" 28 4 3 15	
Eclipse ends	" 28 4 38 42	" 28 5 13 14	30

Duration of Totality, 1m 33s.6.

Angle from N. point, of first contact, 89° towards the W.
Angle from N. point, of last contact, 93° towards the E.
Angle, from Vertex, of first contact, 137° towards the W.
Angle, from Vertex, of last contact, 38° towards the E.
} for *direct* image.

Position S. W. of Talavera de la Reina (Spain).
Long. 5° 10′ W., Lat. 39° 47′ N.

	Local Mean Times. d h m s	Central Standard Mean Times. d h m s	Sun s Altitude. °
Eclipse begins	May 28 2 29 18	May 28 2 49 58	53
Totality begins	" 28 3 46 2	" 28 4 6 42	39
Totality ends	" 28 3 47 29	" 28 4 8 9	
Eclipse ends	" 28 4 55 38	" 28 5 16 18	26

Duration of Totality, 1m 27s.4

Angle, from N. point, of	first contact,	88° towards the W.	for *direct* image.
	last contact,	94° towards the E.	
Angle, from Vertex, of	first contact,	140° towards the W.	
	last contact,	38° towards the E.	

Position west of Puerto del Inferno (Spain).
Long. 1° 43′ W., Lat. 38° 38′ N.

	Local Mean Times. d	h	m	s	Central Standard Mean Times. d	h	m	s	Sun's Altitude. °
Eclipse begins	May 28	2	49	40	May 28	2	56	32	49
Totality begins	" 28	4	4	28	" 28	4	11	20	35
Totality ends	" 28	4	5	49	" 28	4	12	41	
Eclipse ends	" 28	5	12	9	" 28	5	19	1	23

Duration of Totality, 1ᵐ 21ˢ.5.

Angle, from N point, of	first contact,	87° towards the W.	for *direct* image.
	last contact,	94° towards the E.	
Angle, from Vertex, of	first contact,	143° towards the W.	
	last contact,	38° towards the E.	

Cape de Sta. Pola (Alicante) Spain.
Long. 0° 30′ W., Lat. 38° 13′ N.

	Local Mean Times. d	h	m	s	Central Standard Mean Times. d	h	m	s	Sun's Altitude. °
Eclipse begins	May 28	2	56	47	May 28	2	58	47	48
Totality begins	" 28	4	10	52	" 28	4	12	52	34
Totality ends	" 28	4	12	11	" 28	4	14	11	
Eclipse ends	" 28	5	17	55	" 28	5	19	55	21

Duration of Totality, 1ᵐ 19ˢ.4.

Angle, from N. point, of	first contact,	87° towards the W.	for *direct* image.
	last contact,	94° towards the E.	
Angle, from Vertex, of	first contact,	144° towards the W.	
	last contact,	38° towards the E.	

The accompanying map of the line of totality will show the parts of Spain, Portugal, Algeria and Tunis from which this eclipse can be observed. It will be seen that the track, after leaving Spain near Alicante, crosses the Mediterranean and enters Africa close to Algiers.

We may be perfectly certain that the astronomers of the United States and France will man the beginning and the end of the line quite efficiently. It is clear, therefore, that the attention of British astronomers with serious work to do will be directed to the observing stations in Spain and Portugal.

The weather chances were stated by Professor Arcimis in a former number of *Nature*,* and may be considered excellent.

There are many branches of work, such as securing photographs of the corona, in which amateurs may do good service. For them the well-found steamers leaving Marseilles may make the coast near Algiers more convenient.—*Nature*, Dec. 28, 1899.

* Vol. lix. p. 439.

ORIGIN OF THE LUNAR FORMATIONS.*

Various theories have been advanced at different times to explain the origin of the lunar craters, but the chief difficulty that astronomers have heretofore met has been to account for the gigantic scale upon which they are formed. In the series of experiments presently to be described, artificial craters have been constructed resembling those found at present upon the Moon. Since in the earlier experiments no recourse is had to capillary action, or to the explosion of gases, there seems to be no natural limit set to the size of the formations that may be produced by this method, either naturally or artificially. In the explosive experiments described later other features are illustrated. I should state that this investigation was suggested by a letter from Mr. J. B. Hannay, published in *Nature*, 1892, Vol. XLVII, p, 7. In it he describes some minute craterlets naturally produced in solidifying iron slag It seemed to me worth while to repeat these experiments, and to obtain if possible some substance more readily manipulated than melted iron. The substance which I found best suited to the purpose was paraffine. This material melts at so low a temperature that it can be readily handled in the viscous form, while at the same time it becomes quite hard and firm at ordinary temperatures. Like the materials composing the crust of the Earth, it contracts on solidifying, the change in volume in both cases being rather large.

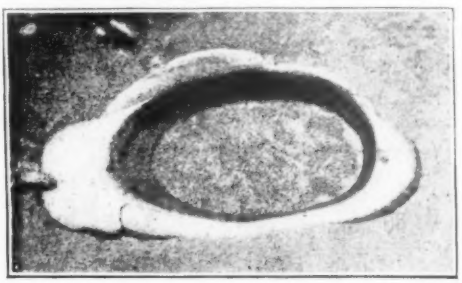


FIG. 14.

The paraffine was melted in an enamelled ware pan, measuring three and a half inches deep by eight in diameter, over a small spirit lamp. By employing a small source of heat the paraffine

* From Vol. 32, pt. 2 of the Annals of Harvard College Observatory, by William H. Pickering.

was melted locally above the flame, and soon formed a little hole in the surface crust measuring about one quarter of an inch in diameter. That portion of the liquid in contact with the bottom of the pan was at a much higher temperature than that above it, and was forced upwards by the heat, rapidly enlarging the hole formed in the crust above it. The hole retained its circular or elliptical form, and continued to enlarge as long as the hot liquid was brought in contact with it. As soon as it had reached a convenient size the lamp was extinguished, and the cooling process begun. As the lower regions of the paraffine cooled they contracted, and the liquid surface dropped, leaving a smoothly cut elliptical pit (Figure 14)*. The sides were at first quite shelving, but by reheating the fluid once or twice they became steeper, and even overhung in some places. Probably a rapid cooling at the surface, and a more rapid contraction of the fluid, obtained by using a larger reservoir, would accomplish the same result. If the contraction is allowed to proceed too far, however, the floor of the crater pit becomes concave, and may even be broken through by the pressure of the atmosphere.

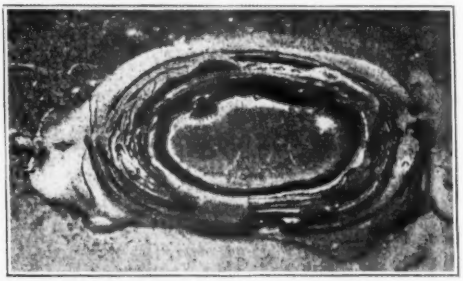


Fig. 15.

In Mr. Hannay's letter he refers to the former very powerful influence of the tides upon the liquids contained within, and upon the surface of the Moon. This tidal action was imitated by inserting a brass tube one inch in diameter and twelve inches long in the paraffine when it was first melted. The tube was fitted with a wooden piston packed loosely with cotton flannel. By working this piston up and down, the melted pariffine could be made alternately to rise and fall inside the craters formed by it, and the cooling process could be hastened when desired by blow-

* Number of Figure in Vol. 32, pt. 2, H. C. O. Annals.

ing upon the liquid surface. Craters (Figures 15 and 16) were formed in the same manner as the first one, excepting that after extinguishing the lamp the tidal action was brought into play, alternately pumping the liquid up to the rim of the crater, where it partially solidified, leaving a little ring of solid parffine, and then drawing it down again into the interior, where it soon partly remelted, preparatory to a renewed elevation. This tidal action was continued until the fluid became quite viscous, solidifying into little hills and ridges inside the crater, and later as the hardening surface was dragged out of shape by the pumping of the liquid below it, little cracks were formed around the edges and across the bottom of the crater, like the rills seen in similar situations upon the Moon.

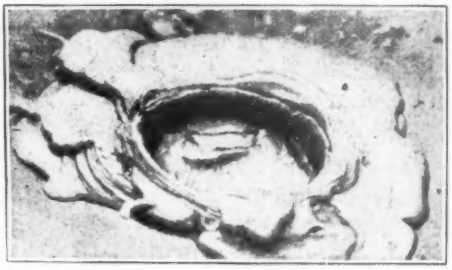


Fig. 16.

If now, we raise the piston high enough, and wait for air to get underneath it, we may force this down into the melted paraffine. The result is an explosion, in which the paraffine may shoot up several feet in the air. If care is taken, however, the jets may be confined to the height of a few inches. A cone is soon formed (Figure 17), and the liquid paraffine trickles down the slopes in miniature lava streams. As the cooling process goes on the paraffine comes out in bubbles, like soap suds, which break and rapidly build up the cone. If the process is continued further, partially solid lumps of paraffine are projected into the air, falling down upon the outer slopes of the cone. The crater now gradually narrows, and if care is not taken will soon become clogged. With care many well known volcanic phenomena may be repeated, such, for instance, as the shifting of crater to one side, and the formation of a succession of crater rings and semi-circles. Also the bursting out of new craters near the base of the original

cone. Indeed, the investigator is likely to perform this experiment involuntary, if he permits the main vent to get partially clogged, and applies too much heat below. The introduction of air seems to transport us at once from lunar to terrestrial scenes, although in the case of the Earth the tides of course have nothing to do with the matter, their place being taken by irregularly recurring explosions of steam.

Fig. 17.

Applying now the results of our experiments to the case of the Moon, we may conceive that the order of formation was somewhat as follows. We will start with the Moon in the form of a liquid or viscous sphere, revolving about the Earth, and close to its surface. Under these circumstances the tides would be of enormous power, and quite unlike in magnitude anything at present existing upon the Earth. Those constituents of the Moon having the least specific gravity would float upon the surface and soon solidify, forming a thin crust. Whether this occurred before or after the solidification of the central core through pressure is of no consequence. As it solidified the crust would contract, forming cracks, which would be enlarged at points into circular holes or craters by the hot liquid interior, while the remaining portions of the crack would become filled with fluid from the interior, which would slowly harden and become part of the continuous surface. We have an illustration this very process arrested in the act, in the case of the great rill of Hyginus, and the small craters distributed along its length. Hyginus is probably a later formation, however, as, if the crust had been thin, the process would have been completed, the craters enlarged, and the rill filled up.

When the process first began, numerous comparatively small holes would form one after another. These holes would continue to enlarge, retaining their circular form, as the hot liquid was

forced through them, until the action was stopped by a sufficiently thick crust forming upon the liquid surface. In the mean time the tremendous tides engendered by our Earth, coursing through the imprisoned liquid interior, would fracture the thin and brittle crust in fresh places, where the same process would be repeated. When the crust was thin the enlargement of the crater would proceed rapidly, and the aperture might attain considerable dimensions before the restraining crust was formed, but as the original crust thickened, and the passage connecting the aperture with the liquid interior lengthened, we should find that the craters formed would be smaller, but more numerous. We should thus expect, in general, that the older the crater the larger it would be, and that the smaller craters would impinge upon the larger ones, and not *vice versa*. An examination of the lunar surface shows this to be the case. The older and larger craters, like Clavius, Albategnius, and many others near the south pole, are pitted and sometimes almost concealed by numerous smaller and later craters, while craters of more moderate size, like Tycho and Copernicus, are comparatively free from such intrusions.

It can be shown that the maximum surface tension exerted by the Earth upon the Moon is exerted upon the great circle forming the limb, and tends to separate the two hemispheres with a force which at the mean distance of the two bodies amounts to a tension of 9.6 pounds on the square inch. When the Moon was at one-tenth of its present distance from the Earth, this tension would have been one thousand times as great, and would have been sufficient to shatter it to pieces had it then existed in the solid form. If, however, it were fluid or viscous, as we have supposed, the effect would have been merely to produce an enormous tide, as has been shown by Professor Darwin. In the mean time, if the Moon revolved rapidly on its axis, so that all portions of its surface were presented successively to the Earth, this maximum strain would be felt successively by all portions of its surface, the tendency being to separate, or crack it, in a meridional direction. We should thus expect to find that the earlier formations would have a tendency to lie in lines in a north and south direction. This we find actually to be the case with the craters that we have been discussing, particularly the larger ones. This fact has been pointed out by Webb, Neison and others.

The craters of this early period, of which Copernicus is the characteristic example, would be moulded by the enormous tides

into forms resembling Figures 15 and 16. The interior surface of one crater, Wargentin, apparently solidified when the tide which filled it reached to its very rim. The aperture connecting it with the interior had in some way evidently become clogged, and the fluid which had formed the crater was caught as it were in the act, to serve as a clue and perpetual illustration of the process of construction to all future generations. Another crater, Mersenius, has a conspicuously convex interior. This was the case at first with the paraffine crater represented in Figure 15, but subsequent cooling caused it to become concave. If the floors of the lunar craters when they solidified were in general convex, it is evident that the subsequent solidification of the fluid beneath them would tend to make the floor level, thereby producing a compression of the surface, which might well result in the formation of a central peak or ridge. If the paraffine model had been constructed upon a larger scale, and the contraction of the fluid beneath it had been allowed to proceed more slowly, it is thought that this result might have been obtained. As it was, a tendency to form small ridges was noticed. In Figure 16 the internal surface of the crater was artificially broken, thereby producing the central mound.

As the cooling process continued, regions deeper down solidified and contracted. The upper layers, having now become completely solid, would not contract at the same rate, with the fall of temperature, and the result would be that the surface of the Moon, instead of being too small, would now be too large for its interior. When this "critical epoch" occurred, the formation of craters would for a time almost cease. The result would be a local subsidence with a considerable local evolution of heat, although the temperature of the Moon as a whole would still continue to diminish. If the heat so developed were sufficient to overcome the latent heat of solidification a considerable portion of the subsident area might be melted, while portions of the original crust carrying their ancient craters with them, would sink slowly beneath the liquid surface, the process of destruction continuing as long as the supply of heat lasted.

In the mean time the Moon would have receded much farther from the Earth, and the tides would have accordingly greatly diminished in their intensity. The subsident areas would in general be large in extent, such as the Maria Imbrium, Serenitatis, and Crisium. The darker color of their floors would seem to indicate that they were formed from another kind of material, which, coming from a considerable depth, had united and mixed

with the lighter colored molten matter which had formed the original surface. In these *maria* we often see the outlines of old crater rings which have been partially melted down and absorbed in the subsequent eruption of melted matter from the interior. Since in all cases the melting progresses outward from a centre, we see why it is that these large seas, like the smaller craters, all retain the approximately circular shape. In some cases where the original crust has subsided, it has melted in the thinnest places only, such as the bottoms of the deepest craters. Thus Plato probably had originally an interior like that of Copernicus, but the melting process which destroyed the bottom was not carried far enough to ruin its walls also, as was partially done in the case of many of the older craters. The elevation of the surfaces of the *maria* probably indicates their relative age, the lower ones being formed last.

(TO BE CONTINUED.)

SPECTROSCOPIC NOTES.

The approaching total eclipse of the Sun May 28, 1900, will be elaborately observed, and should yield some valuable spectroscopic results. As the path of totality passes through such an accessible district in this country the number of well equipped expeditions should be unusually large, while with favorable weather there should be a host of general observers. With New Orleans, Mobile, Raleigh, and Norfolk in the path of totality, thousands can hope to see the corona with no greater inconvenience than going out of doors; while not a few will regard a view of the corona ample reward for traveling a considerable distance.

The probability of a clear sky at the time of totality, as shown by weather observations covering a number of years, varies considerably for different parts of the path. The best prospect for good weather is in the highest elevation in northern Georgia and eastern Alabama, decreasing gradually toward the Gulf coast in one direction and the Atlantic coast in the other. The path of totality on land in this hemisphere is so long that even with a general storm it will be quite possible to have clear weather for a part of the path, and with this in view the extreme southwest should not be altogether neglected. Local fog or flying clouds may add interest and excitement. In case of partial cloudiness in any district observers should be scattered; for this, without diminishing the chances of any individual, increases vastly the probability that the eclipse will be seen by some at least of the party.

For the powerful spectroscopes of various types there will be work in plenty, in the accurate determination of the revised position of the corona line; possibly in the measurement of the velocity of rotation of the corona; and in the study of the flash spectrum at the instants of beginning and end of totality. With the most modest spectroscope the gaseous character of the corona may be shown, and the relative brightness of the weak continuous spectrum may be studied.

The European and African end of the path of totality, passing through Por-

tugal (Coimbra), Spain (Alicante), and Algiers, will be occupied by a number of parties and many general observers. Baron de la Baume Pluvinel on behalf of the French Astronomical Society has visited Spain to ascertain the weather prospects at various points and to arrange for the accommodation of intending visitors. The British Astronomical Association in case a sufficient number express an intention of going will arrange an expedition much after the character of the one to Vadso, Norway, in 1896. A steamer will be chartered to leave Southampton May 18, and after touching at Cadiz to land observers for the centre of Spain, and at Alicante to land those who expect to observe at that point, the ship will proceed to Algiers May 24, and will remain there till after the eclipse; leaving Algiers May 25, touching at Alicante, Gibraltar, and Lisbon, will arrive at Southampton June 4.

The prizes announced by the French Academy of Sciences for 1900 include the Janssen prize, a gold medal, for the most important discovery in physical astronomy.

The report of the Superintendent of the United States Naval Observatory states that the difficulties involved in using a lens only visually corrected for photographing star spectra have been remedied by the insertion of a correcting lens of 2.09 inches aperture, which alters the minimum focus from λ 5270 in the yellow-green to λ 4341 in the violet.

The variable star 2852 V Puppis has recently been studied by Mr. A. W. Roberts at Lovedale, South Africa (*Astronomical Journal* No. 477). He assigns it to the Algol class with a period of 1.5 days. In 1886 Mr. Stanly Williams supected variation and suggested a period of 4.2 days. In 1896 Professor Pickering found the star to be a spectroscopic binary with a period, about double that given by Mr. Roberts, of 3.115 days. Mr. Roberts' observations are consistent with the assumption of the two components, slightly unequal in brightness, revolving in an orbit nearly circular and only slightly inclined; the distance between the surfaces of the stars being less than their semidiameter.

PLANET NOTES FOR MARCH.

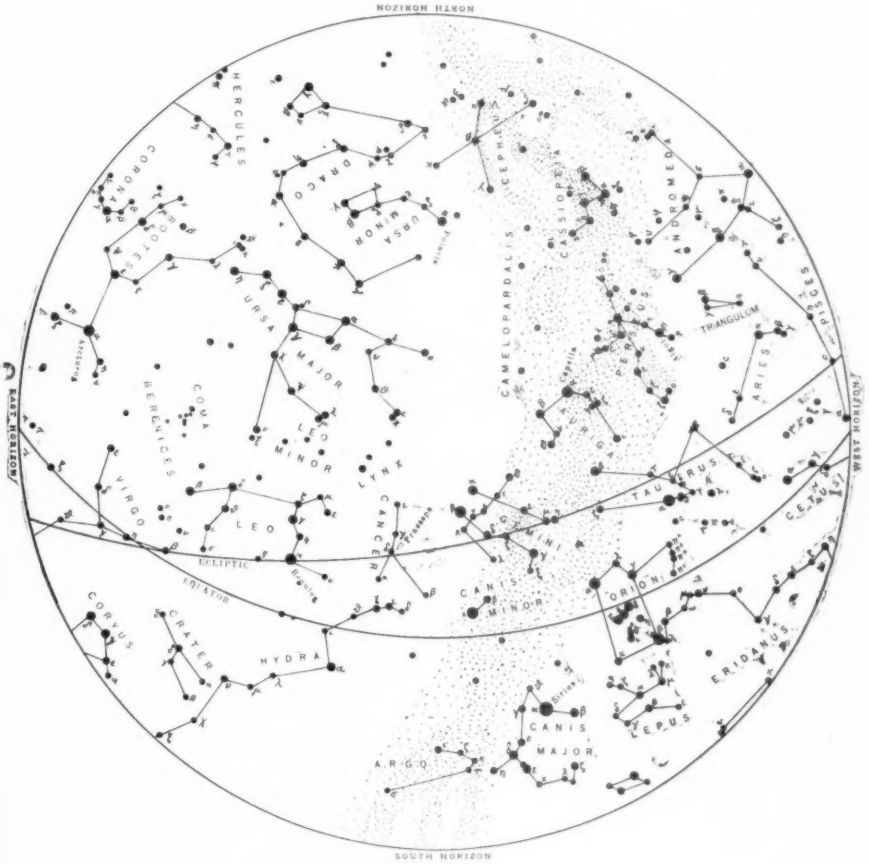
H. C. WILSON.

Mercury is now visible as "evening star" and will continue to be visible to the naked eye for a couple of weeks. Look toward the western horizon about seven o'clock. Mercury is brighter than any star in the vicinity, and ruddy in color because of its low altitude. The planet will be at greatest elongation east from the Sun, 18° 16′, on March 7. On the 24th Mercury will be at inferior conjunction and a couple of weeks later become visible as morning star.

Venus lights up the western sky in the evening with her brilliant rays, causing opaque objects to cast quite perceptible shadows in her light. One can easily see this planet with the naked eye in full sunlight, at any time during a clear afternoon, when once her place is pointed out. Venus disc is gibbous, about half way between the quarter and full phases, and is waning quite rapidly in phase while her light is increasing because of her approach to the Earth.

Mars **is morning star but too nearly in line with the Sun to be observed.**

Jupiter **can be seen in the morning toward the south, but at a low altitude, so that it is not worth the while losing sleep to study the planet.**



THE CONSTELLATIONS AT 9 P. M., MARCH 1, 1900.

Saturn and *Uranus* also are toward the southeast in the morning, not far from Jupiter, but at low altiudes. Uranus will be at quadrature March 3 and Saturn in the same aspect on March 25.

Neptune will be at quadrature east of the Sun on the 14th, and may be observed in the early evening, in the constellation Taurus: R. A. March 15, $5^h\ 35^m$; Decl. $+\ 22°\ 5'$. It will move very slowly eastward, being now at the turn of the western loop in its annual path.

The Moon.

		Phases.	Rises. (Central Standard Time at Northfield; Local Time 13m less.) h m	Sets. h m
Mar.	7	First Quarter.....	10 09 A. M.	1 59 A. M.
	16	Full Moon.....	7 06 P. M.	6 29 "
	23	Last Quarter.....	1 10 A. M.	10 13 "
	30	New Moon.....	5 27 "	6 55 P. M.

Occultations Visible at Washington.

Date. 1900.	Star's Name.	Magnitude.	IMMERSION. Washington M. T. h m	Angle f'm N pt. °	EMERSION. Washington M. T. h m	Angle f'm N pt. °	Duration. h m
Mar. 5	δ Arietis	4.0	11 25	57	12 09	293	0 44
13	14 Sextantis	6.6	12 38	167	13 36	258	0 58
14	36 Sextantis	6.6	7 11	51	7 40	5	0 29
14	55 Leonis	6.2	15 36	88	16 34	323	0 58
14	57 Leonis	6.9	16 08	141	17 06	269	0 58
23	Saturn	...	13 31	100	14 38	260	1 07

The occultation of Saturn will be visible only in the eastern part of the United States, and there it will be so close to the horizon that the immersion will be almost hopeless of observation. In Europe and Africa the conditions will be much more favorable.

VARIABLE STARS.

J. A. PARKHURST.

Maxima and Minima of Long Period Variables.

1900 April.

MAXIMA.

	Mag.	Day.
434 S Piscium	8.6	29
1981 S Camelopardalis	8.4	16
2100 U Orionis	7.0	17
2735 U Canis minoris	8.7	30
3244 S Pyxidis	8.3	3
3264 W Cancri	9.6	13
3425 X Hydrae	8.4	30
— - Virginis	8	6
4849 R Canum Ven.	6.4	2
5465 R Trianguli Austr.	6.7	5
5583 X Librae	9.7	9
5675 V Coronae	7.4	12
5776 X Scorpii	10.0	10
5831 S Scorpii	9.7	23
6062 RR Scorpii	7.3	5
6225 RS Herculis	8.0	2
7045 R Cygni	7.0	1
7118 X Aquilae	8.6	16
7192 Z Cygni	7.8	2
7404 R Microscopii	8.0	1
7448 W Aquarii	8.0	6
7450 V Aquarii	8.1	10

MAXIMA, Con't.

	Mag.	Day.
7468 T Aquarii	7.2	20
7560 R Vulpeculae	8.0	1
— - Pegasi	9	9
7792 SS Cygni	8.5	14?
7907 U Aquarii	9.7	25
8600 R Cassiopeae	6.0	27

MINIMA.

243 U Cassiopeae	<15	11
973 T Arietis	9.5	28
806 *o* Ceti	9	10
1805 V Orionis	<13	6
2478 R Lyncis	<13	29
3186 T Cancri	9.9	20
4492 Y Virginis	12.2	30
5338 U Bootis	12.8	2
5677 R Serpentis	13	6
6044 S Herculis	12	4
6849 R Aquilae	11.2	4
6943 T Sagittae	9.6	27
7428 V Cygni	13.5	20
7456 RR Cygni	9.5	29

NOTES TO LONG PERIOD EPHEMERIS.

1) The dates are taken from Dr. Hartwig's ephemeris in Vol. 34 of the *Vierteljahrsschrift*, part 4. The star numbers and magnitudes are taken from Chandler's Third Catalogue, with a few exceptions.

2) The Star —— — Virginis is at $12^h\ 39^m\ 54^s$, $+ 4°\ 56'.1$, (1855).

3) The star —— — Pegasi is at $21^h\ 14^m\ 8^s$, $+ 13°\ 50'.3$, (1855). See No. 3521 of the *Nachrichten* and Nos. 457, 465 and 473 of the *Astronomical Journal*.

Minima of the Variable Stars of the Algol Type.

(Given to the nearest hour in Greenwich Time.)

1900 April.

U CEPHEI.

	d	h
April	4	15
	9	14
	14	14
	19	14
	24	13
	29	13

ALGOL.

	d	h
April	17	13
	23	7

R CANIS MAJ.

Every 8th min.
$P = 1^d\ 3^h.3$

	d	h
April	1	14
	10	16
	19	18
	28	20

S. CANCRI.

	d	h
April	3	17
	22	16

S VELORUM.

	d	h
April	23	22
	29	20

δ LIBRAE.

	d	h
April	1	14
	2	22
	8	14
	10	21
	15	13
	17	21
	22	13
	24	21
	29	12

U CORONAE.

	d	h
April	1	12
	4	23
	8	10
	11	21
	15	8
	18	18
	25	16

U OPHIUCHI.

Every 10th min.
$P = 20.1^h$

	d	h
April	4	21
	13	6
	21	16
	30	1

RS SAGITTARII.

	d	h
April	4	11
	6	21
	11	17
	16	13
	18	23
	23	19
	28	15

DM. + 45°3062.

	d	h
April	1	17
	6	7
	10	20
	15	10
	20	0
	24	14
	29	3

DM. + 12°3557.

	d	h
April	1	16
	2	14
	3	11
	7	22
	8	19
	9	16
	10	14
	11	11
	15	22
	16	19
	17	16
	18	14
	19	11
	23	22
	24	19
	25	17
	26	14
	27	11

W. DELPHINI.

	d	h
April	11	20
	16	16

AUTHORITIES FOR ALGOL-TYPE EPHEMERIS.—The times for the above ephemeris are taken from Dr. Hartwig's paper in the *Vierteljahrsschrift* with the following exceptions:

1) For R Canis Majoris, S Velorum and RS Sagittarii they were computed from the elements in Chandler's Third Catalogue.

2) For DM. + 12°3557 Luizet's elements, in No. 3596 of the *Nachrichten* were used.

CORRECTION TO THE ALGOL-TYPE EPHEMERIS IN THE FEBRUARY NUMBER.—As noted at the top of page 100, the times for part of the ephemeris were expressed in *civil* time instead of *astronomical* time, but through an error in making up the form the correction was separated from the ephemeris, so that there was danger of its being overlooked. A note from the editors of the *Observatory* gives the source of the original error in the adoption of *civil* time in

the French *Annuaire du Bureau des Longitudes* from which the ephemeris was taken.

VARIABLE STAR SECTION OF THE BRITISH ASTRONOMICAL ASSOCIATION.—Col. Markwick has lately been appointed Director of this Section. He is an accomplished variable star observer and doubtless the Section will flourish under his direction. The following item from his introductory address will interest American observers. "Out of 165 observations of maxima and minima reviewed in the last 6 numbers of the *Journal* (of the British Astronomical Association) 135 were made in America."

VARIABLES IN THE REVISED EDITION OF YOUNG'S GENERAL ASTRONOMY.—A considerable improvement is seen in the light-curves of typical variables, over those given in the first edition. Notably that of Mira corresponds with that given by Dr. Nyland, which was reproduced in Vol. VI, page 413 of this Journal.

SS CYGNI.—In spite of generally unfavorable weather the maximum noted in the February number, page 100, was observed well enough to determine its character. The rise occurred between Dec. 31 and Jan. 2, the maximum about Jan. 7, at 8.4 magnitude, and normal light was reached about Jan. 19, giving a typical long maximum. If the abnormal maximum described in the January number be left out of account, the previous normal period lasted 55 days, just about the usual length. The abnormal maximum has evidently not disturbed the usual order. The number of observations of the January maximum reported so far are as follows:

Zaccheus Daniel	6,	J. A. Parkhurst	10,
David Flanery	1,	W. E. Sperra	4.

U GEMINORUM.—Mr. Sperra has published his observations of the January maximum in No. 476 of the *Astronomical Journal*, showing that the rise took place between 1899 Dec. 30 and 31. In connection with the observations of Mr. Daniel and the writer it is seen that the maximum was passed about Jan. 2 and normal light was reached Jan. 7 or 8. Mr. Daniel is following the star through its normal light with the 10-inch refractor of the Bucknell Observatory.

ANDERSON'S NEW VARIABLE IN HERCULES, which was charted on page 45 of the January number, was found fainter than the 13th magnitude by Mr. Daniel 1899 Nov. 23 and 28. It afterwards rose rather rapidly, for on Feb. 1 I found it only two or three steps fainter than the comparison star *a*, whose DM magnitude is 9.0. The star is thus seen to have a considerable range and a fairly rapid rate of variation. Its place for 1900 is—

R. A. $17^h\ 55^m\ 25^s$, Decl. $+ 19°\ 29'\ 20''$,

thus bringing it into good position for morning observation.

A NEW ALGOL-TYPE VARIABLE.—Professor W. Ceraski, director of the Moscow Observatory, prints the following note in No. 3614 of the *Nachrichten.*

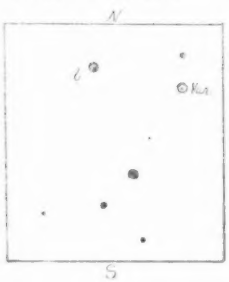
"From a study of the photographs taken by my assistant, M. Blajke, Madam L. Ceraski has found a new variable in the position,

R. A.	19^h	40^m	$59^s.7$	Decl. $+ 32°$ $21'$ $6''$,	(1855)
	19	42	33.4	$+ 32$ 27 34	(1900)

The position was found from one of the plates, the coördinates of the fundamental stars being taken from the Leyden Zones.

Studying other photographs of the same region, M. Blajke has found that the star was invisible on 4 plates, and on 15 it was constant in light, making it probable that it belongs to the Algol-type.

On the 16th of December of this year, at $5^h\ 3^m$, Moscow Mean Time, M. Blajke found the star fainter than usual, the minimum had taken place a few hours before and it was approaching normal light.



From all the proceding a period of $6^d\ 0^h\ 9^m.4$ has been deduced, a minimum occurred 1899 December 15, $23^h.3$, Greenwich Mean Time, the error in the minimum may reach $1\frac{1}{2}^h$, that of the period will probably not exceed $0^m.1$.

The accompanying chart shows the variable and neighboring stars."

Scale of the charts.* The chart given by Ceraski is about 7′ by 8′. Its relation to the DM chart can be seen by the stars *a* and *b*, which are lettered on both. The DM chart also contains the variable χ Cygni at $19^h\ 45^m\ 0^s$, $+32°\ 33'.0$, which is now rising towards maximum.

The plates on which the star was constant† in light were taken—

1)	1895	Sept.	24	11^h	50^m	-13^h	32^m,	Moscow	Mean Time
2)	1895	Oct.	12	6	45	−11	45	"	" "
3)	1898	May	12	11	50	−13	35	"	" "
4)	1898	July	29	12	20	−13	25	"	" "

The variable is usually about the 10th magnitude, at minimum it is 12th magnitude or fainter.

For some time the minimum will take place during daylight, when it cannot be observed.

COMET AND ASTEROID NOTES.

Comet *a* 1900 (Giacobini).—A faint comet was discovered by Giacobini at Nice on Jan. 31 in the constellation Eridanus about 10° directly south of the star α Ceti. Its motion is northwesterly and rather slow. No elements reached us until Feb. 28, when the elements and ephemeris by Perrine, given below, were received by telegram from John Ritchie, Jr., Boston, Mass. As seen in our 16-inch telescope in moonlight, Feb. 5, the comet was exceedingly faint and difficult to observe. Bad weather and the lack of an ephemeris prevented later observations.

ELEMENTS OF COMET *a* 1900 BY C. D. PERRINE.

T = April 29.08, 1900 Gr. M. T.
ω = 24° 37′
Ω = 40 25
i = 146 25
q = 1.3289

EPHEMERIS.

		R. A. h	m	s	Dec. °	′	Light.
Feb.	26	2	10	32	+1	43	0.85
Mar.	2	2	05	36	2	56	
	6	2	01	52	4	07	
	10	1	58	32	+5	15	0.82

* The second cut was lost by engraver or in transit.

† NOTE. This seems to be an error for "invisible," as printed it is "invariable."

The date of the first observation used in the computation was Feb. 3 and the interval from the first to the second more than 10 days, and from the second to the third 5 days. The elements, therefore, ought to be fairly reliable. The comet according to the ephemeris is now in the neck of Cetus and will soon enter Aries.

New Elements of Asteroid 1899 EY.—Mr. Otto Knopf gives new elements of this planet, in *Astronomische Nachrichten*, No. 3621, based on observations on the dates Dec. 7 and 29 and Jan. 21.

Epoch 1900 Jan. 0.0 Berlin M. T.

$$\left.\begin{array}{ll} M = & 19^\circ\ 43'\ 24''.0 \\ \omega = & 322\ \ 58\ \ 41\ .4 \\ \Omega = & 89\ \ 55\ \ 39\ .0 \\ i = & 15\ \ 13\ \ 23\ .9 \end{array}\right\} 1900.0 \left\{\begin{array}{l} \varphi = 4^\circ\ 28'\ 33''.5 \\ \mu = 668''.1835 \\ \log a = 0.433407 \end{array}\right.$$

With these he has computed the following ephemeris, for Berlin, midnight:

	R. A. (h m s)	Dec. (° ′)	log r	log Δ	Mag.
Mar. 5	4 31 03	+ 21 49.1	0.4544	0.4418	10.7
7	32 58	22 00.0			
9	34 57	22 10.9	0.4547	0.4506	10.8
11	37 00	22 21.6			
13	39 06	22 32.2	0.4550	0.4592	10.8
15	41 16	22 42.7			
17	43 29	22 53.1	0.4553	0.4675	10.9
19	45 46	23 03.3			
21	48 06	23 13.4	0.4556	0.4756	10.9
23	50 29	23 23.3			
25	52 55	23 33.0	0.4559	0.4834	11.0
27	55 24	23 42.5			
29	4 57 56	23 51.9	0.4562	0.4909	11.0
31	5 00 31	+ 24 01.1			

GENERAL NOTES.

We are delayed, again, in getting some important illustrations ready for this issue. We know our subscribers would be better pleased if we were able to issue our publication earlier. We are trying to catch up, and still hope to do so for the April number.

Beginning of the Twentieth Century.—It is astonishing to see how thinking people are confused about the beginning of the twentieth century. There can be no uncertainty about this, if it is remembered that there is no zero year in our calendar before the Christian era, at its beginning or since. Year 2 did not begin until the end of year 1, year 20 did not begin until the end of year 19; hence year 1901 will not begin until the end of year 1900. We are not yet in the twentieth century.

The Nebulae of the Pleiades.—Two fine specimens of the recent work of the Crossley Reflector in photographing the Nebulae of the Pleiades have just come to hand by favor of Professor James E. Keeler, Director of the Lick Observatory, Mount Hamilton, California. One of these positives is the Maia Nebula, and the other is the Merope Nebula. The dark background of each positive covers a space of 5 inches square in each picture. One or both of these fine pictures will appear in our next number.

Rays from Bright Stars in Photographs.—Professor E. E. Barnard, of Yerkes Observatory, Williams Bay, Wisconsin, was a visitor at the February meeting of the Royal Astronomical Society, London, England. While the work of reflecting telescopes was under discussion, Professor Barnard was asked for his views, being cordially welcomed and addressed as an authority on stellar photography. In reply he said: "I have not had experience in the use of the reflecting telescope, but I have generally had the impression that it is not at all comparable with the refractor, especially for visual work; but the things that have been done in the last few years in the way of astronomical photography with the reflector have led me to think that when properly mounted, as Mr. Christie has said, it is the better instrument for taking nebulæ. It is far better than the refractor for that work. I was much interested in the very beautiful picture of the Pleiades, and there was one thing I was rather struck with. I do not know exactly what is the reason, but there seems to be a total absence in this particular picture of the objectionable rays from the brighter stars that are seen in the photographs made with the reflector. I do not know how these are got rid of, but I believe it is due to the supports of the small mirror. I should be glad to have a little more information on this subject. I should like to know why the bright stars in the field are not accompanied by nebulosity and how these rather objectionable defects have been got rid of."

In reply to this Dr. Common said: "It is the fact that two supports (to the small mirror) produce four rays, three produce six, but four produce four. So you can have four supports with less injury to the image than with three."

We learn from a friend that Professor Barnard sailed for America, Feb. 24.

Comet *a* 1900 (Giacobini).—On the afternoon of February 1, I received a telegram from Professor Edward C. Pickering, announcing the discovery of this comet. The following night being clear and dark, I observed the new comet with the ten inch Clark telescope of the Bucknell Observatory. The comet was pretty faint. I could just glimpse it with the three inch finder, but my four inch refractor showed it very distinctly. In the ten inch refractor, it appeared small and round with a strong central condensation. No train was seen, but a nucleus was suspected. I saw the comet again on February 2, but the conditions were not so good as they were on the previous night. Since that time, I have not seen it, owing to clouds and moonlight. No observations for position could be made because the micrometer is not in working order.

BUCKNELL UNIVERSITY, Lewisburg, Penn., ZACCHEUS DANIEL.
1900 February 16.

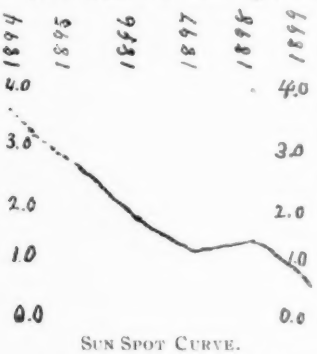
Dawn of the Twentieth Century.—"The first people to live in the twentieth century will be the Friendly Islanders, for the date-line, as it may be called, lies in the Pacific Ocean just to the east of their group," writes John Ritchie, Jr., in the January Ladies' Home Journal, of "Where the next century will really begin." "At that time, although it will be already Tuesday to them, all the rest of the world will be enjoying some phase of Monday, the last day of the nineteenth century [December 31, 1900]. At Melbourne the people will be going to bed for it will be nearly ten o'clock; at Manila it will be two hours earlier in the evening; at Calcutta the English residents will be sitting at their Monday afternoon dinner, for it will be about six o'clock; and in London, 'Big Ben,' in the House of Commons, will be striking the hour of noon. In Boston, New York and Washington half the people will be eating breakfast on Monday

morning, while Chicago will be barely conscious of the dawn. At the same moment San Francisco will be in the deepest sleep of what is popularly called Sunday night, though really the early dark hours of Monday morning, and half the Pacific will be wrapped in the darkness of the same morning hours, which become earlier to the west, until at Midway or Brooks Island it will be but a few minutes past midnight of Sunday night."

Five Years of Sun Spots.—Late in the fall of 1894 our telescope was mounted. Soon afterward we began observing sun spots, and making record of the number seen at each observation.

The record has many breaks, as to its continuity, but possibly it is worth preserving.

The record which is given below was begun Jan. 1, 1895 and closed the last of Dec., 1899.



SUN SPOT CURVE.

	No. of Observations.	Average No. of Spots.
1895	123	24
1896	100	15
1897	76	10
1898	105	11
1899	38	6

DRAKE UNIVERSITY, Des Moines, Ia. W. A. CRUSENBURY.

Mme. Ceraski's Second Algol Variable.—Another remarkable variable star of the Algol class has been discovered by Mme. Ceraski, and is announced in the *Astron. Nach.* 151, 223. The position for 1900 is R. A. $= 19^h\ 42^m.7$, Decl. $= +32°\ 28'$. From an examination of the Draper Memorial photographs of this star, it appears that while the star has its full brightness on 45 of them, on several of the early photographs it is so faint that they must have been taken when the star was near minimum. The Moscow photographs furnish the means of determining the period from an interval of four years, the Harvard photographs increase this interval to nine years. The following table gives, in the first seven lines, the results derived from the Harvard photographs; the next four, the results of the Moscow photographs; and the last line gives the estimate of M. Blajko. The times of minima as found by Professor Ceraski may be expressed by the formula J. D. 2,415,004.971 + $6^d.0065$ E. Measures of four Harvard photographs when the star had its full brightness gave the photographic magnitudes, 11.00, 10.80, 10.74, and 10.79; mean 10.83. The value of E, derived from the above formula; the year, month and day; the Greenwich Mean Time of the middle of the exposure; the corresponding time expressed in Julian Days and decimals; and the duration of the exposure in minutes are given in the first five columns of the table. The sixth column gives the photographic magnitude, and the seventh, the phase computed by means of the formula mentioned above. The error in the ephemeris is given in the eighth column, and is derived from an approximate light curve. It appears that the period is too long by about $0^m.6$, and if this correction is applied, the errors have the values given in the ninth column. The tenth column gives the mean photographic magnitude, during the entire time of exposure, derived from the corrected ephemeris and light curve.

E.	Date.			G. M. T.		J. D.	Ex.	Magn.	Phase.	O-C.	O-C'.	C. M.
	y	*m*	*d*	*h*	*m*		*m*					
— 580	1890	6	2	16	32	1521.689	27	11.81	+ .488	+ .25	+ .01	11.7
— 570	1890	8	1	14	20	1581.597	13	12.75	+ .331	+ .24	+ .02	12.7
— 570	1890	8	1	14	57	1581.623	20	12.22	+ .357	+ .16	— .06	12.5
— 557	1890	10	8	11	53	1659.495	10	< 12.4	+ .145	. .	. .	12.8
— 508	1891	8	8	16	07	1953.672	20	< 11.7	+ .003	. .	. .	12.1
— 443	1892	9	2	14	44	2344.614	16	10.96	+ .522	+ .18	.00	11.0
— 325	1894	8	11	15	07	3052.630	10	10.90	— .228	+ .13	—.01	10.9
— 257	1895	9	24	10	11	3461.424	102	< 12	+ .124	. .	. .	12.9
— 254	1895	10	12	6	45	3479.281	300	< 12	— .039	. .	. .	12.5
— 97	1898	5	12	10	12	4422.425	105	< 12	+ .085	. .	. .	12.9
— 84	1898	7	29	10	22	4500.432	125	< 12	+ .008	. .	. .	12.9
— 0	1899	12	16	3	33	5005.106	125	Ft.	+ .135	. .	. .	12.5

It appears from this table that while the formula of Professor Ceraski satisfies all the later observations, it is not confirmed by the early observations. For instance, according to this formula the star should have had nearly its full brightness on the first three photographs. On the other hand, all the observations are satisfied by the corrected formula, in which the period is $6^d\ 0^h\ 8^m.8$. As soon as we obtain accurate observations of subsequent minima, these combined with the photographs taken in 1890, will give a much more precise formula. A comparison of the sixth and tenth columns shows that the observed and computed magnitudes differ in one case only by more than one tenth. A slight defect partially covers the image of the variable on the second plate taken August 1, 1890, and thus renders the measured value too bright. The period differs so little from exactly 6 days that for a long time the minima cannot be observed in certain longitudes. Accordingly, while valuable observations may be obtained next autumn in Europe, or better still in Asia, minima cannot be observed in America until the following year.

Five stars of the Algol class, S Cancri, U Cephei, W Delphini, + 45°3062, and the star here discussed are especially interesting, owing to the large variation in their light, which amounts to about two magnitudes in each case. It is remarkable that two of these were found by Mme. Ceraski, and one by her distinguished husband.

EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY Circular No. 47.
February 12, 1900.

Leonids Seen at Scott Observatory, Park College, November, 1899.—November 13. Sky was overcast with heavy clouds from midnight till daylight. No meteors were visible.

November 14. A heavy fog overhung the landscape from midnight till two o'clock, when it began to settle down, though a thin haze prevailed all over the sky till half past four o'clock, Central Standard Time. From that time till dawn, which came about six o'clock, the sky was reasonably clear. For the record made, see annexed pages.

November 15. Thin hazy clouds prevailed all night. At times these were so dense that not even the Moon was visible through them; then, again, stars as bright as Regulus or Aldebaran would show dimly; and, very rarely, γ and ϵ Leonis would show quite distinctly. Stars of fifth magnitude could not be seen at any time during the night.

November 16. Heavy clouds spread over the sky. Rain came once and light-

ning played frequently. The clouds began to break away about half past five o'clock, and for a few minutes, once just before 5:30 and again just before six o'clock, the "sickle" in Leo came into view.

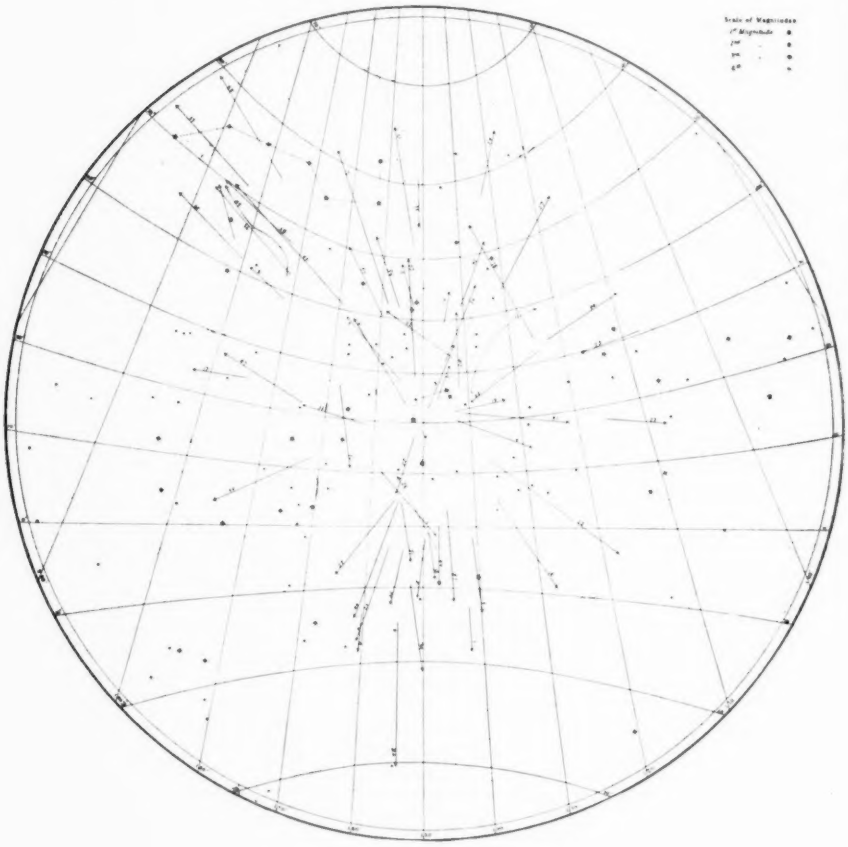


CHART OF LEONIDS.

By Professor S. P. Brackett, Park College, Mo., Nov. 13-16, 1899.

November 17. The sky was tolerably clear from midnight till three o'clock and from that time till full daylight as clear as it could possibly be.

On all these nights a large force of watchers, composed of students in the Junior class of Park College, volunteered their services and assisted the writer in carefully kept observations. Probably, in all, a dozen small meteors, nearly or quite all distant from the radiant, were ignored and no record kept of them. Some of these came from the direction of the radiant but most of them did not. The writer most gladly attributes a large portion of the success (small as it was

on account of clouds) to the efficient help rendered by the young ladies and gentlemen of the student body, Juniors and Seniors in Park College. The following is the record:

Scott Observatory is in Lat. + 39° 03′ 18″ and Long. 94° 41′ 26″ W.

TUESDAY NIGHT.

Time. h	m	s	Color.	Mag.	Leonid or Not.
14	08	45	B	3.5	L
	17	08	B	3	L
	17	27	B	5	L
	38	02	B	5	?
	39	55	B	3	N
	45	05	B	2	N
	45	07	B	2.2	L
	46	03	Y	3.3	N
	47	02	B	5	L
	55	04	B	4	L
14	59	03	B	4	L
15	01	40	R	2	N
	02	06	B	3	L
	03	59	B	3	N
	04	01	B	3	N
	04	45	R	1	L
	06	07	B	3	L
	08	05	R	2	N
	12	59	Y	3	N
	14	20	B	4.5	L
	18	08	B	6	L
	18	41	R	2.5	L
	19	06	B	5	L
	20	11	B	6	L
	21	20	R	1	L
	22	25	B	4	N
	23	04	R	4	L
	30	21	R	3	N
	36	00	B	3	L
	45	04	B	— 1	L
	47	17	B	4	L
	50	42	R	2	N
	52	03	B	3	L
15	52	05	B	2	L
16	08	02	Y	4	N
	10	12	B	4	L
	13	01	B	5	L
	17	13	B	5	L
	20	07	R	5	?
	22	25	R	2.5	L
	30	45	R	2	L
	31	05	B	2	L
	34	11	B	5	L
	35	50	Y	5	L
	37	06	RY	3	L
	37	45	B	3.5	L
	40	03	B	6	L
	46	55	Y	4	L
	47	00	RY	2	L
	48	01	B	5	L
	48	35	R	2.5	L
	50	01	B	3	L
	52	26	B	4	L
	54	02	B	4	L
16	55	49	B	3	L
16	56	25	R	2	L
	57	28	Y	2	L
	58	15	R	2	L
16	59	48	R	5	N
17	00	10	B	4	L
	03	00	R	3	L
	05	30	R	2	L
	06	25	B	3	N
	07	07	B	2	L
	08	45	R	2	L
	09	27	B	2	L
	10	01	B	3	L
	11	48	B	1.5	L
	12	02	B	6v	L
	12	40	Y	4	L
	15	03	B	4	L
	15	05	B	2	L
	15	10	Y	2	L
	15	21	B	1.5	L
	15	46	B	— 2	N
	15	55	R	1	L
	16	30	B	5	L
	17	02	B	2	L
	18	10	B	— 1.5	L
	18	15	R	4	L
	20	05	B	— 2	L
	20	16	B	3	L
	20	50	Y	5	N
	21	04	B	1	L
	21	16	Y	3	N
	21	45	B	3.5	L
	22	04	B	3	N
	22	19	Y	4	L
	23	00	B	4	N
	23	07	B	6	L
	24	03	B	2	L
	24	05	B	4	N
	25	32	B	— 2	L
	25	45	B	— 3	L
	28	05	B	5	L
	29	01	B	6	?
	30	14	B	— 2	L
	30	25	B	3	L
	31	20	B	— 2	L
	32	20	B	1	L
	32	45	Y	4	L
	33	41	R	5	L
	34	05	R	2	L
	34	36	B	4	L
	35	05	Y	4	L
	36	55	B	3	L
	36	57	B	2	L
	37	45	Y	4	N
	38	25	B	— 2	L
17	39	06	Y	3	L

Time. h	m	s	Color.	Mag.	Leonid or Not.	Time. h	m	s	Color.	Mag.	Leonid or Not.
17	40	14	B	2	L	17	49	08	B	5	L
	40	25	R	3	L		52	15	B	3	L
	41	03	B	5	N		52	24	B	3	L
	42	06	B	2	L		54	01	B	4	L
	42	55	B	3	L		55	13	B	1.5	L
	43	41	B	2	L		56	34	Y	1	L
	44	00	B	5	L		56	52	R	3	L
	44	31	B	5	N		57	03	B	2	L
	44	47	Y	5	L		58	04	B	1	L
	46	03	B	6	L	17	59	11	B	5	L
	47	25	B	4	L	18	01	03	B	3	L
	48	32	B	2	L		02	01	B	5	L

WEDNESDAY NIGHT.

Time. h	m	s	Color.	Mag.	Leonid or Not.	Time. h	m	s	Color.	Mag.	Leonid or Not.
13	45	29	B	3	L	14	42	34	B	3	L
	55	55	B	3	L		48	08	B. R.	1	L
14	02	20	B	2	L		50	18	B	3	L
	06	22	B	4	L		52	15	B. R.	— 2	N
	10	32	R	5	N		36	04	B	2	L
	19	45	R	3	L		58	17	R	4	N
	21	14	R	4	N	14	58	56	B	5	L
	21	43	R	3	N	15	03	48	B	3	N
	21	45	R	3	L		11	24	B	4	N
	22	54	R	4	L		11	25	Y	4	L
	23	05	B	4	L		20	41	Y	3	N
	24	53	B	4	L		41	53	B	2.5	L
	25	46	R	5	L	16	06	10	Y	2	L
	27	32	B	5	L		09	05	B	6	L
	28	25	B. G.	3	L		12	16	Y	1	L
	30	03	B	4	L		17	06	B	6	L
	30	15	Y	2	L		18	35	Y	6	L
	31	53	R	4	L		19	31	B	5	L
	32	15	R	3	L		19	34	R	2	L
	33	04	B	4	L		23	11	B	2	L
	33	23	Y	1	N		23	25	B	4	L
	33	38	B	3	L		25	51	R	1	L
	33	44	B	4	L		47	44	B	4	N
	35	17	B	3	L	16	59	19	R	5	N
	36	19	Y	4	L	17	01	45	bg	1	L
	36	33	R	4	N		03	47	R	4	L
	37	10	B	2	L		04	38	Y	4	L
	38	46	B	4	L		08	51	B	4	L
	41	24	R	5	L		23	15	B	4	L
	41	27	B	4	L	17	31	53	B	4	L
14	42	19	B	3	L						

THURSDAY NIGHT.

Cloudy till nearly dawn.

Time. h	m	s	Color.	Mag.	Leonid or Not.	Time h	m	s	Color.	Mag.	Leonid or Not.
17	49	48	B	— 1	L	17	26	49	R	4	L

FRIDAY NIGHT.

Time. h	m	s	Color.	Mag.	Leonid or Not.	Time. h	m	s	Coror.	Mag.	Leonid or Not.
13	09	17	R	4	N	14	00	07	B	3	N
	11	42	R	3	?		01	12	Y	3	N
	33	10	R	1	L		29	35	Y	1	N

Time. h	m	s	Color.	Mag.	Leonid or Not.	Time. h	m	s	Color.	Mag.	Leonid or Not.
14	40	01	B	4	L	15	52	00	B	2	L
	44	32	B	3	N	15	52	09	B	4	L
	56	39	B	3	L	16	00	01	B	2	N
15	11	04	B	1	L		16	09	B	3	L
	31	47	B	3	L		19	30	B	4	L
	34	58	Y	1	L		24	48	B	4	L
	37	39	R	2	N		26	49	R	4	N
	40	46	B	3	L		32	51	Y	2	L
	43	54	B	3	L		34	43	B	2	L
	44	19	B	1	L		45	04	B	4	L
	45	21	R	6	N	17	01	09	B	4	N
	51	05	B	1	L						

Meteors seen Tuesday night.....134
" " Wednesday night..... 61
" " Thursday night..... 2
" " Friday night..... 29

Total.....226

Probably from a dozen to twenty meteors fell, but so far from the radiant that no record was kept of them. F. P. BRACKETT.

Bulletin of Geography.—"Bulletin of the American Bureau of Geography" is the name of a new publication which is issued under the direction of Edward M. Lehnerts of the State Normal School, Winona, Minn. The first number of this quarterly magazine, which is dated for March, 1900, presents a very creditable appearance. The number of associate editors and the contents of this initial number certainly give promise of large usefulness in its chosen field.

We are especially interested in the article under the title "The points of the compass, and the seasons in teaching Geography in the grades," by Professor John M. Holzinger. His simple illustrations of prominent constellations of stars, and a method of copying and relating bright stars in them is worthy of notice.

Popular Articles on Astronomical Subjects.—The unusual interest in popular articles on astronomical subjects is very noticeable in recent years. In view of this it has seemed to us wise to give larger place to them in the future. In the past two things have stood partially in the way of this: (1) The need of students more or less advanced in the study of astronomy who have asked for, and have needed, such articles as Dr. J. Morrison, of Washington, has furnished from time to time; and (2) the difficulty of getting good popular matter. We have partly overcome these hindrances.

Queries and Short Answers.—1. Please inform one who wishes to know something about Astronomy, what book or books would be best to get. C. B. T.

Answer. For a beginner, Todd's Stars and Telescopes published by Little, Brown & Co., Boston; Holden's Elementary Astronomy, Henry Holt & Co., New York; Howe's Elements of Descriptive Astronomy, Silver Burdett & Co., Chicago; Howe's Study of the Sky, Flood and Vincent, Meadville, Penn.; Young's Lessons in Astronomy, Ginn & Co., Chicago, are a few of the recently published good books. Prices can be obtained by writing to the publishers.

2. Does the top of a wagon wheel, when rolling on the ground, go faster than the bottom? H. S.

A. Yes, if the motion of the two points is thought of in relation to a line

parallel to the ground. No: if thought of in relation to the center of the wheel.

3. If a stick two feet long, and three inches in diameter at one end, be shaved down to a true point at the other end, then balanced it on a knife-edge, and cut into two pieces on the line of balance, which part will weigh the more?

A. Each part weighs the same.

4. Does the Mississippi river run up hill? It does, if the law of gravitation is true. E.

A. It certainly is true that the mouth of the Mississippi river is farther from the center of the Earth than its source; just how much we do not now stop to inquire, but when the effect of the rotation of the Earth and other conditions that enter into its structure are considered, the fact that the river runs south and not north no more disproves the law of gravitation than if it run north, unless it can be shown certainly that the law of gravitation requires the river to flow northward instead of southward. The attempts that have been recently made to disprove the law of gravitation in this way that we have seen depend on very weak and faulty mathematics. It is like trying to polish a diamond point with a broad ax. Well-meaning students need instruction in mathematics.

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